



1
2000

This is to certify that the

thesis entitled

Exploring the Basic Capabilities of LabVIEW

presented by

Heidi Lynn Bartlett

has been accepted towards fulfillment
of the requirements for

M.S. degree in Electrical Engineering

Major professor

Date May 3, 2000



PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.
MAY BE RECALLED with earlier due date if requested.

DATE DUE	DATE DUE	DATE DUE
	FEB 27 2005	
OCT 05 2001		
NOV 17 2002		

EXPLORING THE BASIC CAPABILITIES OF LABVIEW

By

Heidi Lynn Bartlett

A THESIS

**Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of**

MASTER OF SCIENCE

Electrical Engineering

2000

ABSTRACT

EXPLORING LABVIEWS BASIC CAPABILITIES

By

Heidi Lynn Bartlett

Industries are not only looking for college graduates who are knowledgeable in their areas' theory and concepts, but they are also looking for individuals that are familiar with the common software tools in use at their company. Due to this need, the more experience a student has with industry products the more favorably they will be in demand in the job market. This paper is geared towards being a resource and a stepping stone for learning an industry used software product named LabVIEW. In order to achieve this goal, five demonstrations are utilized to illustrate basic LabVIEW concepts. Each demonstration uses electrical engineering concepts to show the different aspects and features of the product. They also outline the process required when developing an experiment and the lessons learned from each. The five demonstrations are a beginning look at the capabilities of LabVIEW. Additional features and capabilities can be explored to find more ways to enhance ones knowledge of LabVIEW.

Dedicated to my family.

ACKNOWLEDGMENTS

I would like to thank and acknowledge the continued support and assistance of Dr. P. David Fisher. I would also like to thank Roxanne Peacock, Brian Wright, John Kelley, Pete Semig, and Nathan Robinson for their assistance.

TABLE OF CONTENTS

ACKNOWLEDGMENTS	iv
TABLE OF CONTENTS.....	v
LIST OF TABLES.....	vi
LIST OF FIGURES	vii
LIST OF ABBREVIATIONS	ix
Chapter 1: Introduction	1
Chapter 2: Background	2
2.1 DATA ACQUISITION	2
2.2 SIGNAL PROCESSING	3
2.3 LABVIEW	5
Chapter 3: Demonstrations	9
3.1 TIME DOMAIN MEASUREMENT: SIGNAL PROCESSING DEMONSTRATION.....	9
3.2 QUASISTATIC MEASUREMENT: THERMISTOR DEMONSTRATION.....	17
3.3 DYNAMIC MEASUREMENT: ACCELEROMETER DEMONSTRATION.....	26
3.4 FREQUENCY MEASUREMENT: TACHOMETER DEMONSTRATION.....	34
3.5 INTERFACING: SIMPLE SORT DEMONSTRATION.....	40
Chapter 4: Conclusions.....	45
APPENDIX A	48
PCI-MIO E SERIES NI-DAQ I/O PIN ASSIGNMENTS ⁹	48
APPENDIX B	49
THERMISTOR RESISTANCE MEASUREMENTS – TEMPERATURE DEMONSTRATION.....	49
APPENDIX C	50
VOLTAGE READINGS FROM HARDWARE CIRCUIT – TEMPERATURE DEMONSTRATION.....	50
APPENDIX D	51
CALCULATED EQUATION VALUES – TEMPERATURE DEMONSTRATION.....	51
APPENDIX E	53
DATA COLLECTED TO FILE FROM – ACCELEROMETER DEMONSTRATION.....	53
APPENDIX F	62
MS VISUAL C++ SOURCE CODE FOR CIN DEMONSTRATION	62
APPENDIX G	63
TUTORIALS	63
Bibliography	66

LIST OF TABLES

Table 3.2.1: Measured and expected values of resistors.....	24
Table 3.2.2: Measured data and calculation data samples.....	25
Table 4.1: Relevant features for each demonstration.....	45

LIST OF FIGURES

Figure 2.3.1: 'Tools' platelet details	8
Figure 3.1.1: Signal generation vi	11
Figure 3.1.2: Sine wave vi	11
Figure 3.1.3: Fourier Transform vi	12
Figure 3.1.4: Amplitude spectrum.....	12
Figure 3.1.5: Diagram view of generated sine wave with Fourier Transform.....	13
Figure 3.1.6: User interface for generated sine wave with Fourier Transform.....	14
Figure 3.1.7: Resulting frequency domain graph In MatLab.....	16
Figure 3.2.1: Wheatstone bridge circuit.....	18
Figure 3.2.2: Displays the data acquisition controls.....	20
Figure 3.2.3: Parameters needed for simple analog input channel.....	21
Figure 3.2.4: Diagram view for single input voltage.....	21
Figure 3.2.5: User interface for single input voltage control.....	22
Figure 3.2.6: Resistance range of thermistor from 0 to 100 degrees C.....	23
Figure 3.2.7: Calculated verses measured voltage from 0 to 100 degrees C.....	25
Figure 3.3.1 Accelerometer equivalent circuit ³	27
Figure 3.3.2 Accelerometer demonstration structure.....	28
Figure 3.3.3 Close-up of accelerometer base.....	29
Figure 3.3.4: The four components of analog data capture.....	31
Figure 3.3.5: Diagram view for accelerometer demonstration.....	32
Figure 3.3.6: User interface view for accelerometer demonstration.....	33
Figure 3.4.1: Schematic for transmissive optoschmitt sensor ⁴	35
Figure 3.4.2: Spinning wheel with sensors.....	36

Figure 3.4.3: Graph and calculate phase difference vi.....	37
Figure 3.4.4: Power and frequency vi.....	38
Figure 3.4.4:Diagram view for tachometer demonstration.....	38
Figure 3.4.5: User interface for tachometer demonstration.....	39
Figure 3.5.1: Code interface node	41
Figure 3.5.2: Diagram view of CIN demonstration.....	43
Figure 3.5.3: User interface view of CIN demonstration.....	43

LIST OF ABBREVIATIONS

CIN.....	Code Interface Node
dc.....	Direct Current
I/O.....	Input/Output
Ni-DAQ	National Instruments Data Acquisition
vi.....	Virtual Instrument

Chapter 1: Introduction

In industry, software applications are used to help engineers develop and produce new technologies. These tools are used throughout a range of fields including, but not limited to, mechanical, chemical and electrical engineering. When students graduate from a university, additional to theory and concept knowledge, industries are looking for individuals who are familiar with and even are proficient with the common software tools used in their company. In order to provide students with that experience, these tools need to be introduced at the university undergraduate and graduate levels.

One tool that is used in the industry for testing and simulation is LabVIEW. LabVIEW was introduced to Michigan State University (MSU) in 1997. This software tool is available to MSU students, though its use is limited to a few select courses. This paper will give an overview of LabVIEW with demonstrations that can be recreated by anyone wishing to learn LabVIEW. Although the demonstrations use electrical engineering concepts, the general tools and understanding of LabVIEW can be applied to other engineering and physics fields. If any student wants to become familiar with LabVIEW due to a future job or just to have the knowledge of the product, this thesis is a first start resource to some of the features and capabilities of LabVIEW.

Chapter 2: Background

Both data acquisition and signal processing are used in a wide range of applications. This chapter will cover the background needed for a general understanding of the concepts of data acquisition and signal processing. These concepts are used and referenced throughout the paper. Additionally, an introduction and preview of LabVIEW will be covered.

2.1 DATA ACQUISITION

Before describing the demonstrations that illustrate the different aspects of LabVIEW, we first have to understand the underlining concept of *data acquisition*. Data acquisition is one of the key components demonstrated in the following experiments. By definition data acquisition is simply the collection of data. The data in this case is either a voltage or current source from an external device or circuit, and LabVIEW is the tool that is collecting it.

An interface between the external source and LabVIEW is needed. The card is installed on the same machine that the program LabVIEW is located. A data acquisition card or GPIB to an instrument is needed for any machine that needs to collect data from an outside source. In the following experiments, a Ni-DAQ PCI-MIO-16E-4 card is used. This card allows 68 different I/O pin assignments. Pins are referred to as channels. Channel options include analog input and output pins, digital input and output pins, reference grounds, voltage

source (+5V), triggers, counters and converters just to name a few.⁹ The pin assignments can be found in Appendix A and also the PCI-MIO E Series User Manual. LabVIEW and the Ni-DAQ card are products of National Instruments Corporation.

This data acquisition card is the connecting line between the hardware and software portions of all the experiments. The Ni-DAQ card is considered to be a 'device' by LabVIEW. One station may contain many devices. For the following experiments, there is only one device. Each device is assigned a number with the Ni-DAQ drivers that are installed on the system. The first device is noted as 0 (zero) and additional devices increment starting with 1. The data acquisition controls used are explained, as needed, within each experiment.

2.2 SIGNAL PROCESSING

Signals can be acquired through the data acquisition process detailed in the above section. Once a wave signal is obtained, on some occasions, the signal needs to be processed. LabVIEW has built in signal processing tools that make it easier to process a signal. Signals that are imported through the Ni-DAQ card are in the time domain. The time domain is the representation of the signal at the instant of time at which it was sampled. In many cases there is need to view signals in the frequency domain. The frequency domain is the representation of the signal in terms of its individual frequency components. The frequency domain is more useful in determining characteristics of the signal and possibly the system it came from.

The discrete Fourier transform (DFT) algorithm is used to transpose the signal from the time domain into the frequency domain. A Fourier series is the combination of sinusoids at the signals fundamental frequency and integer multiplies. Given N number of samples sampled in the time domain signal x, the discrete Fourier Transform is X_k , where

$$X_k = \sum_{i=0}^{N-1} x_i e^{-j2\pi i k / N}$$

for $k = 0, 1, 2, \dots, N-1$.

The time domain and the frequency domain have the same number of samples, N. With a given sampling rate of f_s Hz, the sampling interval in the time domain is Δt , where

$$\Delta t = \frac{1}{f_s}.$$

Corresponding to Δt in the time domain, the frequency spacing in the frequency domain Δf , where

$$\Delta f = \frac{f_s}{N} = \frac{1}{N\Delta t}.$$

To increase the resolution of the frequency Δf you must either increase the number of samples for the same f_s , or decrease the sampling rate f_s keeping the number of samples N constant.

In the discrete Fourier series, X_k will always be complex, although the imaginary part may be zero. Because this is complex, the amplitude and the phase of the signal are the two pieces that can be derived from the

transformation. Given a real signal $x[i]$, the transformation is symmetric if the magnitude has the properties

$$|X[k]| = |X[N - k]|$$

and the phase has the properties

$$\text{phase}(X[k]) = -\text{phase}(X[N - k]) .$$

Knowing the transformation from the time domain to the frequency domain is important for knowing the behavior of the signal. The above equations are built into LabVIEW, though in order to understand the output that is obtained, it is helpful to know where the values have come from in case additional processing is needed.

2.3 LABVIEW

In most engineering fields, engineers need tools to help them design, build and manufacture their creations. In today's technology driven world it is easy to find a variety of tools to help with almost every situation. However, deciding on which tool to use can be difficult. Hardware tools such as lab instruments and software tools such as programming languages are commonly used by an electrical or computer engineer. LabVIEW, a programming tool that has been out on the market for a while since 1986, targets engineers who need to work both in the hardware and software environments.⁵

Developed and marketed by National Instruments, LabVIEW is a graphical programming language. Its graphical interface gives the impression that it is just

an application that converts its 'pictures' to lines of code where they can not be seen, but this is not the case. The language, called 'G', is made up of graphical components that are strung together and configured to get the desired results. There are no limitations that inhibit the user from creating a standard component that does not already exist. The program does have to be compiled after each change is made before the changes will be active in a run of the program. When compared directly to conventional programming languages LabVIEW will appear to be slower on performance but when compared to other graphical programming languages the speed increase is noticeable. There are no text lines of code to write or to scan for errors. There is no need to search through code to find a '0' (zero) that was typed instead of an 'o' or a single quote that needed to be a double quote.

LabVIEW interfaces with standard lab instruments. There is also internal software that can simulate lab instruments internal to the program. This feature allows the user to test and simulate a program in an 'ideal' setting in order to fine tune the program before connecting it to the real circuits or instruments. Data acquisition cards called Ni-DAQ (National Instruments Data Acquisition) cards are available for interfacing to other instruments and hardwired circuits. Cards have connections, or channels, that support analog and digital signals for input and output. This allows a LabVIEW program, called a virtual instrument (vi), to interact with the hardware. Sending and receiving signals back and forth through the data acquisition card allows the program to make decisions based on the events of external hardware.

LabVIEW is used in many disciplines, including Mechanical Engineering, Electrical Engineering and Physics. Many applications of LabVIEW include one or more of the following: process control, automated testing, image processions and data acquisition. For example, a classic use of LabVIEW would be a project requiring data sampling over a long period of time. The LabVIEW program includes a loop to read the data at a given time interval in order to sample and record the data to a file. This allows a hands-free environment. A computer sitting in a room taking samples of the room temperature for a forty-eight hour period gets a more timely and precise reading than a technician doing the same job. A second example is pulling extreme amounts of data from an instrument within a short period. LabVIEW can go beyond human limitations of recording accurate data.

LabVIEW has two components, the user interface view and the diagram view. The interface view is where the interactive controls and displays are located. The diagram view is where the underlying logic and 'code' of the program is located. Each view has a unique toolbar that holds only the components that can be used in that view.

For the user interface a menu of controls is available. These controls consist of switches, graphs and numeric displays and controls. There are two modes available for most of the components, control and indicator. The control option allows a user to change the value of the component during or prior to running the program. The program can be run in a continuous or single instance mode. There are two buttons located on the main menu bar. The single instance button

will run iteration of the program then stop while the continuous mode will continue to run the program one instance after another until a stop button is pushed on the main menu bar. The indicator option only displays the results fed into it from a different object. The control or indicator option is applied to a control that is placed in the user interface view. Under the diagram view, the functions menu is available. Functions include 'while' and 'do' loops, numeric operators and data acquisition controls. The main logic and sequencing of the program resides within the diagram view. The user interface view allows the user to see and interact with the results of the program.

The 'tools' palate seen in Figure 2.3.1 is available in both views. The tools consist of an operate value, position/size/select, edit text, connect wire, object popup, scroll window, set/clear breakpoint, probe data, get color and set color. The four most utilized tools, 'Operate Value' Hand tool, 'Position/Size/Select' Arrow tool, 'Edit Text' tool and the 'Connect Wire' tool, are briefly described in more detail.



-  **'Operate Value' Hand tool:** To change values on the user interface. This mimics a users hand to minipulate dials on the user interface.
-  **'Position/Size/Select' Arrow tool:** Used for selecting components in both views in order to move them to a new location.
-  **'Edit Text' Tool:** Used for placing labels on components and changing values in the user interface.
-  **'Connect Wire' Tool:** Used for connecting components in the diagram view.

Figure 2.3.1: 'Tools' pallet details

Chapter 3: Demonstrations

The following experiments demonstrate some of the abilities of LabVIEW.

In the creation each experiment, the same process was used to develop the demonstration. The first step of the process was to identify general concepts that were to be presented. Each concept was chosen to compliment each other in order to cover a large base of possible applications. The concepts that were identified included different levels of data acquisition, signal analysis and ease of use. The capabilities of LabVIEW that could demonstrate these concepts were selected and used throughout the experiments.

The first experiment starts with a very basic example of the signal processing concepts of time vs. frequency domain. The second uses a thermistor to show an example of a quasi-static voltage measurement. The third shows the speed and dynamic data capture techniques of LabVIEW using the output of an accelerometer sensor for its data source. The fourth demonstration uses a spinning disk to display how the data from signal processing can be used to emulate a tachometer. And the fifth demonstrates how to embed external source code into a LabVIEW vi. Each of these experiments is described in detail in the following sections.

3.1 TIME DOMAIN MEASUREMENT: SIGNAL PROCESSING DEMONSTRATION

INTRODUCTION

The purpose of this experiment is to explain and demonstrate the LabVIEW ability to process signals. This experiment will use a signal generated by LabVIEW and display the results for the Fourier Transform.

HARDWARE

There is no external hardware used in this experiment. LabVIEW has the ability to be independent of external hardware components. LabVIEW generates all of the needed signals for this demonstration. This feature is useful for any situations where the signal that is going to be processed is unavailable due to location, dangerous environment or other reasons. For future signal processing, the generated signals can be replaced with signals from external sources via the Ni-DAQ card.

SOFTWARE

LabVIEW is used to generate and process the signal. There are a couple different options when generating a signal. LabVIEW has a very general signal generation vi seen in Figure 3.1.1. This sub-vi allows you to specify the frequency, sampling rate (number of samples/duration), amplitude and offsets. It also lets you choose from a sine, cosine, sawtooth, square, triangle, and increasing and decreasing ramps. The sampling rate must be greater than twice the frequency to meet the Nyquist criterion.

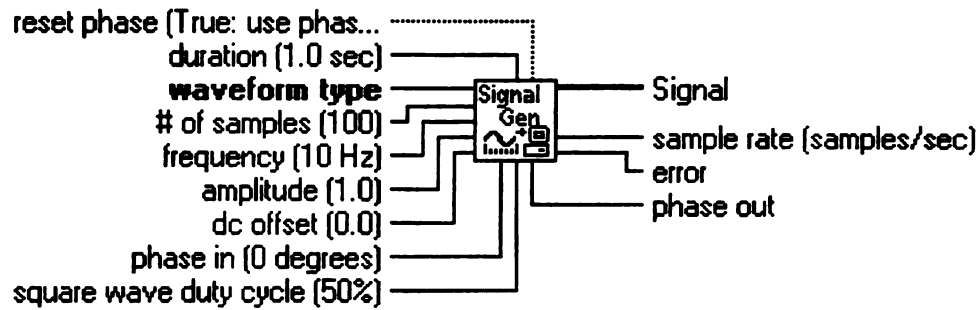


Figure 3.1.1: Signal generation vi

Individual waves can also be created. A sine wave is formed by using the built in sub-vi specifically for sine waves. There are similar vis for other wave types. Similar to the general signal generator you can specify the frequency, amplitude, phase and number of samples. Figure 3.1.2 displays the inputs and outputs needed for the sine wave generation tool. In this incident f represents the normalized frequency (cycles per sample).

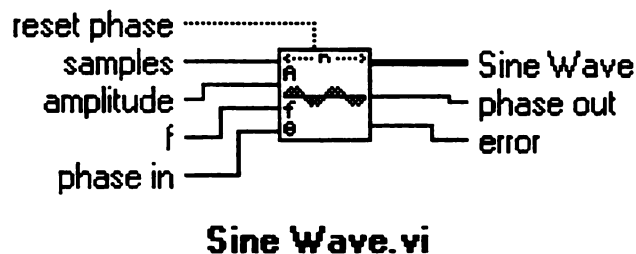


Figure 3.1.2: Sine wave vi

Once the signal is available the waveform needs to be transformed using Fourier Transform to display the signals magnitude and phase in the frequency domain. The sub-vi for the Fourier Transform is straightforward as seen in Figure 3.1.3.

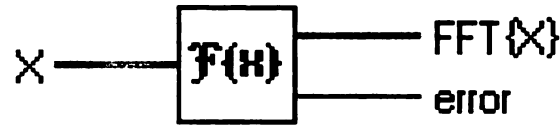


Figure 3.1.3: Fourier Transform vi

Additional to the Fourier Transform vi, the 'Amplitude Spectrum' vi will calculate the phase and magnitude of the time domain signal.

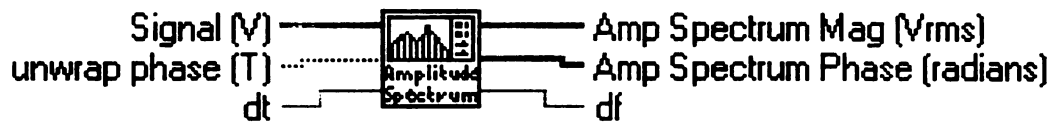


Figure 3.1.4: Amplitude spectrum

The output signal from the Fourier Transform can be linked directly to a graph to display the magnitude and phase information. Figure 3.1.5 displays diagram view where the 'Sine Wave' vi and 'Fourier Transform' vi are linked. The figure also shows the connections to the amplitude spectrum. The normalized frequency has to be calculated from the cycles and sampling rate designated by the operator of the program.

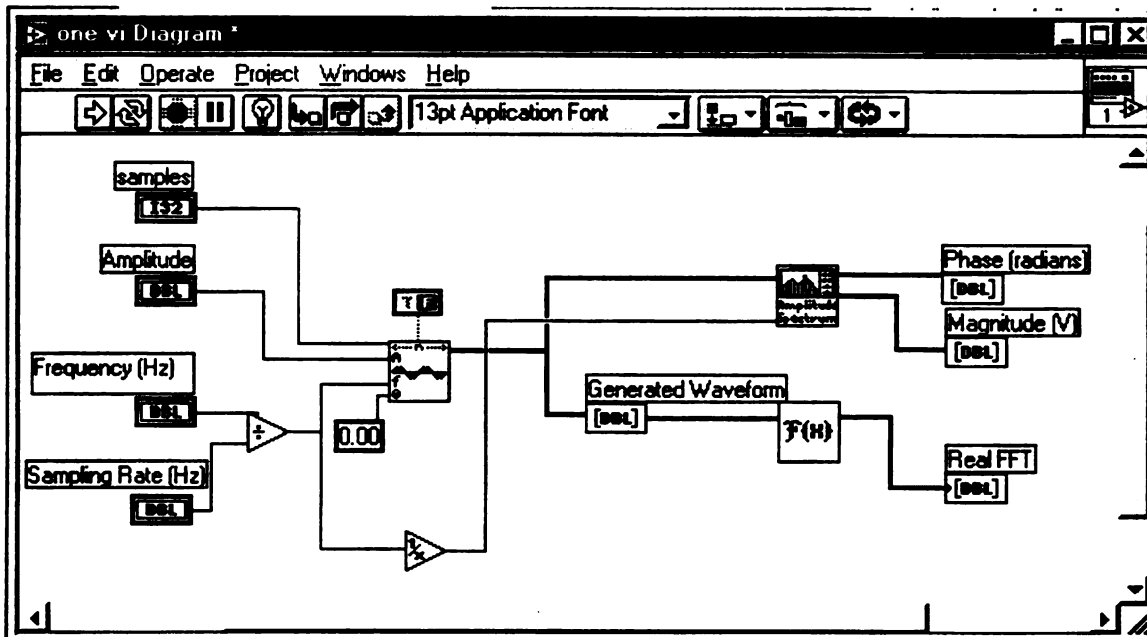


Figure 3.1.5: Diagram view of generated sine wave with Fourier Transform

The sampling period and frequency are also calculated and displayed in the user interface view as seen in Figure 3.1.6. It can be seen under the 'Real FFT' that the first peak of the wave is at 50 Hz, which matches the frequency that was sent for the generated waveform.

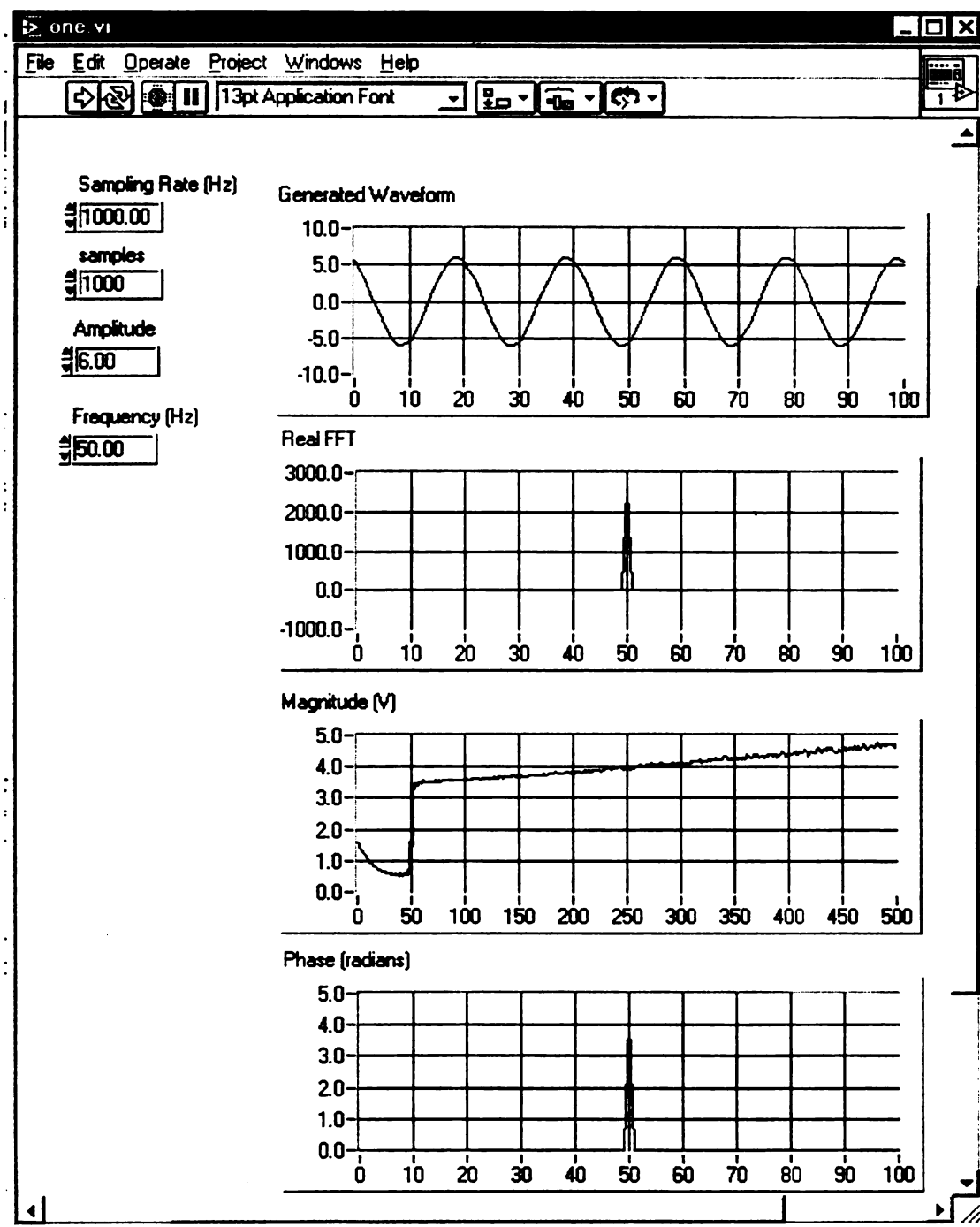


Figure 3.1.6: User interface for generated sine wave with Fourier Transform. The x-axis on the 'Real FFT', 'Magnitude' and 'Phase' is frequency.

CALCULATIONS

To verify the magnitude and phase of the transformed wave, a MatLab simulation is used. Creating a sine wave form with a frequency of 50 Hz in MatLab, we can use the built in Fast Fourier Transform (fft ()) function in MatLab to plot the frequency domain graph.⁷ Below is a sample of the necessary MatLab steps to build the sine wave and create the transform.

```
% Heidi Bartlett
% Calculate FFT in Matlab

% Create the sine wave
t = 0:0.001:1;
x = 5*sin(2*pi*50*t);

% Take Fast Fouriers Transform of sine wave
Y = fft(x,512);

% Take power spectral density
Pyy = Y.*conj(Y)/512;

% Graph the first 257 points
f = 1000*(0:256)/512;
plot(f, Pyy(1:257))
```

Figure 3.1.7 displays the graph that is derived from the above program. The spike is clearly at 50 for the 50Hz frequency that was created. This closely matches the real FFT graph that is displayed by LabVIEW in Figure 3.1.6.

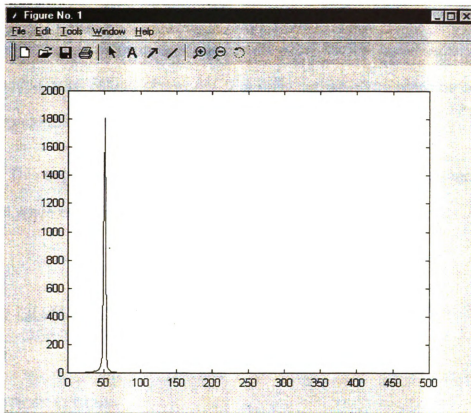


Figure 3.1.7: Resulting frequency domain graph In MatLab

CONCLUSIONS

This experiment demonstrates a small portion of the signal generation and processing ability of LabVIEW. Generating a signal is essential for testing and simulation. In many occasions the signal that needs to be monitored or measured is not located in the lab or development environment. The true signal may be in a dangerous or unavailable location and the signal generation allows for testing of a program without the need to go outside the development environment.

Signal processing can help filter and analysis the signals. Additional programming can be incorporated to act upon, filter or make decisions based on the type or amplitude of a signal. For example, an alarm could be set if the magnitude of a signal was too large or small.

This experiment is focused on learning how the waveform generation tools and wave analysis tools are used in LabVIEW.

3.2 QUASISTATIC MEASUREMENT: THERMISTOR DEMOSTRATION

INTRODUCTION

The purpose of this experiment is to explain and demonstrate the ability of LabVIEW to process a DC voltage through the data acquisition card. This experiment illustrates the steps of setting up the necessary hardware and software portions required. A Wheatstone bridge layout with a thermistor is used to obtain a voltage signal to represent the temperature. LabVIEW then accepts the voltage signal and displays it on a graph.

CIRCUIT DESIGN

Before starting in with LabVIEW, the experimenter determines how the temperature of the room is going to be obtained. LabVIEW has an input analog voltage range of -10 to $+10$ volts. A Wheatstone Bridge is used to take

advantage of its 'balancing point' to simplify the calculations and to stay within the voltage requirements of LabVIEW. Figure 3.2.1 displays the Wheatstone Bridge circuit.

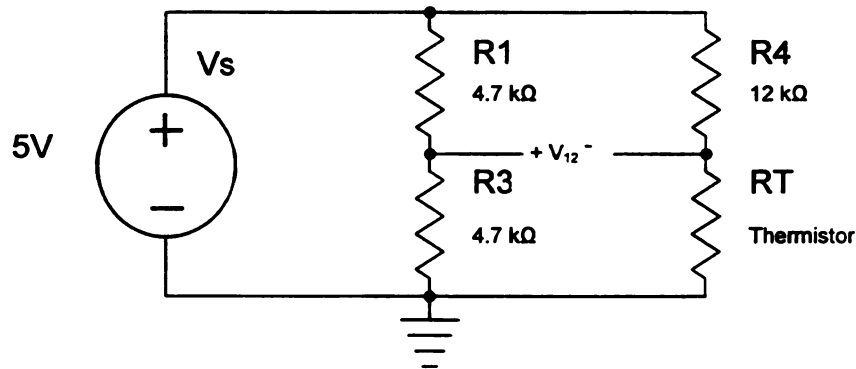


Figure 3.2.1: Wheatstone bridge circuit

The following equations can be derived from the Wheatstone Bridge circuit.

$$V_1 = \frac{R_3}{R_1 + R_3} V_s \quad V_2 = \frac{R_T}{R_4 + R_T} V_s \quad V_{12} = \frac{R_3 R_4 - R_T R_1}{(R_1 + R_3)(R_4 + R_T)} V_s$$

$$\text{Let } R_T = R_{T0} + \Delta R \text{ therefore } V_{12} = \frac{(R_3 R_4 - R_{T0} R_1) - R_1 \Delta R}{(R_1 + R_3)(R_4 + R_{T0} + \Delta R)} V_s$$

Then, at the balance point $R_3 R_4 = R_{T0} R_1$ which simplifies the equation to:

$$V_{12} = \frac{-R_1 \Delta R}{(R_1 + R_3)(R_4 + R_{T0} + \Delta R)} V_s$$

HARDWARE

The main component of the experiment is the thermistor. This device will change resistance depending on the temperature it is exposed to. An Omega® “400” series thermistor probe, precisely model number ON-402-PP, is used. The probe is water resistance and is used for general-purpose type applications. The temperature rating is to 100 degrees C. This range is within the desired temperature range for this experiment. A change in resistance changes the output voltage from the Wheatstone Bridge. LabVIEW processes the voltage and displays it on the graph. The thermistor is calibrated to 2252Ω at 25 degrees C. This value is used to calibrate the reading from LabVIEW. Two 12Ω resistors and a trim pot are used as the three other resistors needed in the Wheatstone bridge. The thermistor is used as the fourth resistor in the bridge.

An Analog Device’s precision instrumentation amplifier is used in this experiment (model AD524). This amplifier has a switching gain between 1, 10, 100 and 1000. A variable gain can also be obtained by using resistors, but only a gain of 10 is needed in this situation.

SOFTWARE

LabVIEW is used to display the voltage output from the temperature circuit. The steps below highlight how to set up LabVIEW to read the voltage source and display it in a graph format. Only a single analog input is needed for this experiment. The ‘AI One Pt’ (analog input one point) analog input control is selected. Figure 3.2.2 displays the data acquisition controls. In future, it would

be feasible to add an output channel to control the heat source of the room that is being monitored.

The analog input channel requires at least two parameters, the device number and channel name. The device number is the number associated with the Ni-DAQ card that is installed. The channel refers to the channel number or pin number that the signal is connected to. The control is displayed in Figure 3.2.3. The output from the control is the data collected. That data is set to a display graph and is visible in the user interface view.

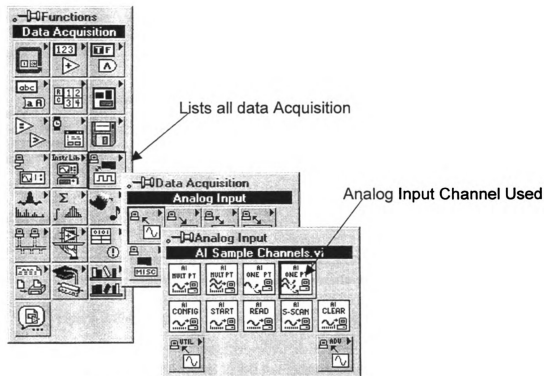


Figure 3.2.2: Displays the data acquisition controls



Figure 3.2.3: Parameters needed for simple analog input channel

In this example, the two controls, device and channel, are set up so that the user can change the values depending on the project. This allows more flexibility in the application and makes it more feasible to be used as a sub-vi in other applications. The background or diagram view is the working part of the program. Figure 3.2.4 displays the diagram view of the vi program. The user interface displays the current input voltage using a numeric display and a waveform chart as shown in Figure 3.2.5. This view allows for a 'user-friendly' interface.

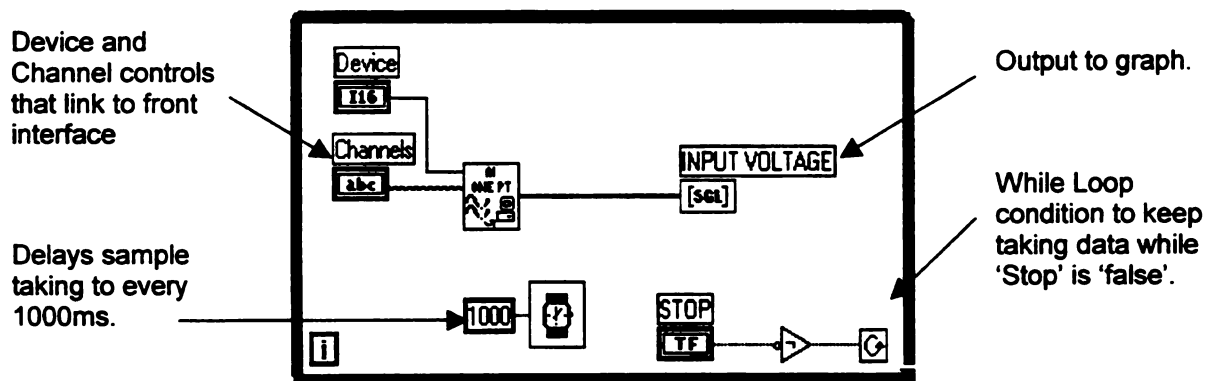


Figure 3.2.4: Diagram view for single input voltage

The program does not need to be run continuously. The 'while' loop incorporated in the diagram view continuously reads voltage from device 0, channel ACH0, until the 'Stop' button is pressed. If the 'run continuous' option is

used, the stop button will not have any effect since the program will start itself and will not stop until the main stop button located on the main menu is used.

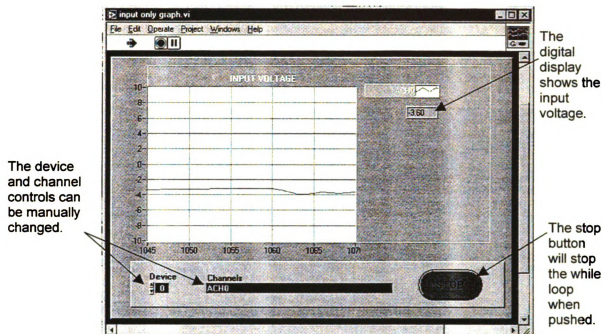


Figure 3.2.5: User interface for single input voltage control

CALCULATIONS

The first step is to test and measure the resistance of the thermistor. A beaker of water is brought to 0 degrees C using ice, as measured by a standard mercury thermometer. The thermistor resistance is manually measured every 2.5 degrees, independent of time, as the water temperature is slowly brought up to 100 degrees C. Figure 3.2.6 displays the results. The raw data is listed in Appendix B.



After the values of the thermistor are measured, those measurements are used in the calculation of the voltages in which that the circuit will function. The recorded values are plugged into the equations derived above.

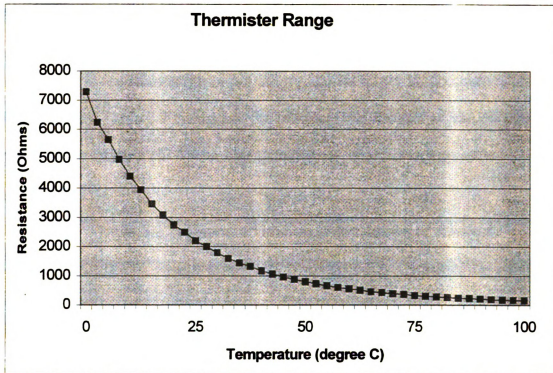


Figure 3.2.6: Resistance range of thermistor from 0 to 100 degrees C

A gain of 10 is needed to amplify the signal to the desired range. Once the calculated range is determined, a measured test is performed to test the circuit. A beaker of water is once again filled with ice and water and the temperature of that water is slowly heated from 0 degrees C and to 100 degrees C. This is the same procedure that is described earlier with just the thermistor, but on this occasion, the voltage both before and after the amplifier is measured and recorded. The temperature is measured and recorded every 2.5 degrees. The calculated values are listed in Appendix D.

The values before and after the amplifier are extremely close, and any variance more likely is caused by human delay of recording the values than by any noise from the amplifier. The values recorded both before and after the amplifier are listed in Appendix C.

In the calculated values, the given resistances are used. The resistance values of the resistors and trim pot are measured to get an accurate reading of the resistors. Table 3.2.1 displays the results. The 'measured values' are obtained by using a HP Multimeter to find each resistors actual value.

Table 3.2.1: Measured and expected values of resistors		
DEVICE	EXPECTED VALUE (K Ω)	MEASURED VALUE(K Ω)
R4	12	11.833
R3	12	11.905
Trim Pot	3.200	3.220

The measured and calculated values are compared and displayed in Figure 3.2.7. Table 2 displays a sampling of data comparing the measured and calculated voltage values.

Table 3.2.2: Measured data and calculation data samples				
TEMP. (DEGREES C)	MEASURED VOLTAGE (V)	CALCULATED VOLTAGE (V)	DIFFERENCE (V)	% ERROR
0	-8.535	-8.371	0.164	1.75
25	2.817	2.777	0.040	1.44
50	7.666	7.408	0.258	3.48
75	9.482	9.188	0.294	3.20
100	10.00	9.873	0.127	1.29

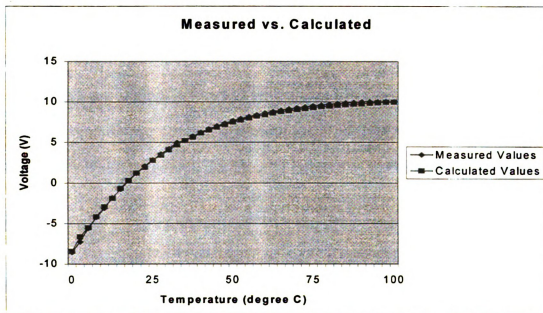


Figure 3.2.7: Calculated verses measured voltage from 0 to 100 degrees C

CONCLUSIONS

The experiment demonstrates how to take an analog voltage from a hardware circuit, feed it into the interface card and display it through LabVIEW. LabVIEW is a useful tool for displaying and recording data. LabVIEW output

abilities have not yet been explored. In a temperature experiment like this, the output channels could also be used.

In the example of heating a beaker of water, if the water temperature needed to be kept within a desired range, LabVIEW could turn on and off the heat source to maintain the temperature. The input channels would read the temperature to make sure it is within the given range. If the temperature went beyond that range; LabVIEW would react by changing its output voltage through an analog output channel, assuming the hardware interface was there to control the heat source, the heat could be lowered or raised as needed. LabVIEW may be programmed to keep the temperature of water or a room within a particular range by utilizing its input and output controls.

This experiment is focused on learning the basics of LabVIEW. Knowing how the input analog controls are configured, how voltages can be displayed and how to configure a channel are all skills needed to perform this experiment.

3.3 DYNAMIC MEASUREMENT: ACCELEROMETER DEMOSTRATION

INTRODUCTION

In this experiment a golf ball is dropped onto a piece of Plexiglas. An accelerometer is attached to the Plexiglas adjacent to where the golf ball impacts. The accelerometer measures the impact of the golf ball on the piece of Plexiglas from different heights and sends a voltage signal to LabVIEW.

CIRCUIT DESIGN

The accelerometer signal needs amplification in order to get an accurate reading. The signal from the accelerometer is amplified by 100 before it is read into LabVIEW. The Analog Device's precision instrumentation amplifier is used again in this experiment (model AD524). A variable gain is statically set to 100 to amplify the signal from the accelerometer. Figure 3.3.1 displays the accelerometer's equivalent circuit.

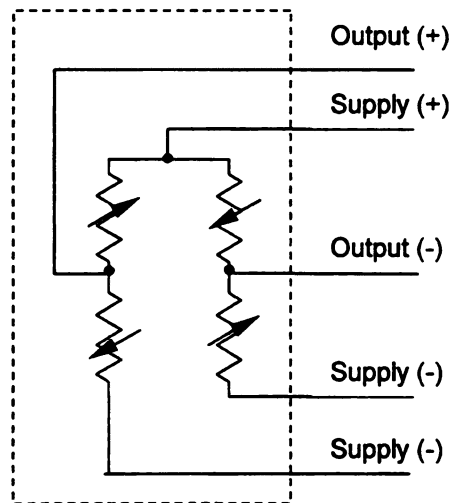


Figure 3.3.1 Accelerometer equivalent circuit³

HARDWARE

A long cylindrical Plexiglas tube sits on top of a piece Plexiglas that is placed on a wooden board. The tube is twenty-four inches high and is marked every two inches starting at four inches up to twenty-two inches. See Figure 3.3.2 for a picture of the structure. At each mark, a small hole is drilled to allow a rod to be placed through the tube. This rod is used to hold the golf ball in place

before releasing it. The golf ball does not directly hit the accelerometer. Rather, the golf ball impacts the base approximately one inch away from where it is glued down to the base as seen in Figure 3.3.3.

The main component of the circuitry is an accelerometer. A general purpose, solid state piezoresistive accelerometer, model 3022, from EG&G IC Sensors is used. The accelerometer sends out a voltage signal that represents the impact of the golf ball applied to the Plexiglas.

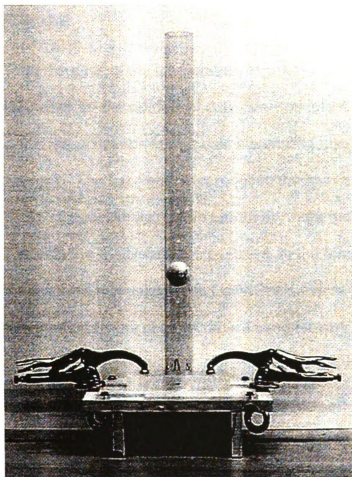


Figure 3.3.2 Accelerometer demonstration structure

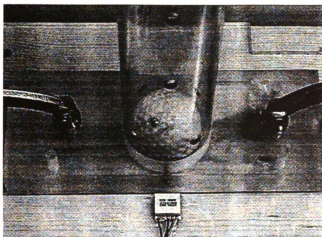


Figure 3.3.3 Close-up of accelerometer base

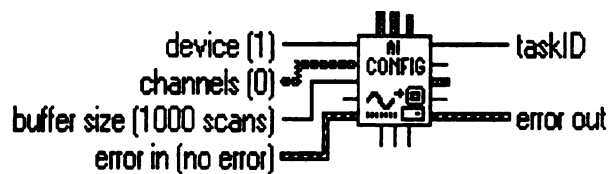
SOFTWARE

In the case of the temperature experiment the temperature change is a slow process, so the reading of data every minute is adequate. However, in the case with the accelerometer, the time sampling rate is crucial to a working experiment. The accelerometer requires thousands of samples per second.

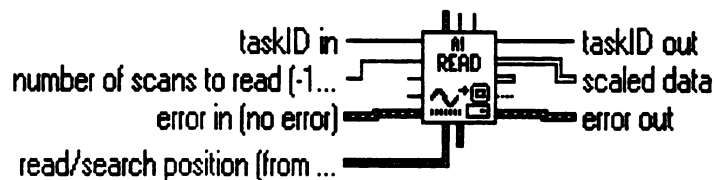
To accomplish this within LabVIEW, more detailed controls need to be used than in the temperature experiment. In the temperature experiment, the data acquisition tool used within LabVIEW is the 'AI One Point.' This is the analog input one input channel device used for very simple, single, analog input data acquisition. The problem with this control is a sampling rate limitation when more than 250 samples per second are needed. A sampling rate of 2000 samples per second is needed to acquire the data from the accelerometer. The reason is that this control combines the functionality of four separate functions; configuration, start, read and clear. Each of these steps makes up the data retrieval from a single analog input channel. Each step of the 'AI One Point'

control is performed for each data sample. This means that in a program that reads in twenty samples of analog input, the connection to the hardware is configured, opened, read and cleared twenty times. When sampling rates need to be increased, this creates a bottleneck and limits the sampling rate.

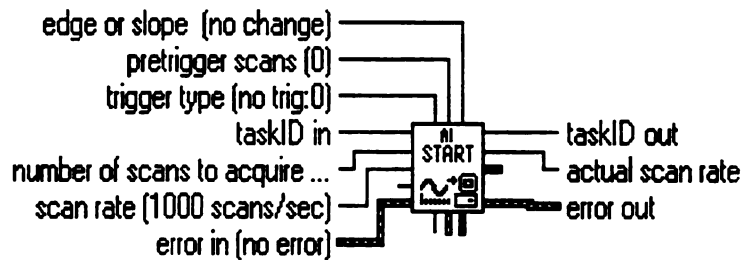
The four individual steps need to be separated so that the channel is configured, then started. The read cycle then continues for the number of reads needed and is then cleared once after all reads are complete. Separating the individual steps speeds up the sampling rate adequate enough to read in data from an accelerometer. The four components 'AI Config', 'AI Start', 'AI Read' and 'AI Clear' listed in figure 3.3.4. The device, channel, and number of total scans are defined within the 'AI Config' vi. The 'AI Start' vi then defines the scan rate and starts listening to the data channel established. The 'AI Read' vi is the component that actually reads in the data; all data prior to this point is not recorded. The read component continues to read until the number of samples specified is read. Unlike the method used in the temperature experiment the configuration and start steps are not repeated for each read. After all reads are complete, the 'AI Clear' vi clears the port configured and closes a connection. A taskID is passed between the four components to mark which data stream it is handling at the time. LabVIEW can handle many data signals from different channels at one time and the taskID identifies what channel it is handling.



AI Config.vi



AI Read.vi



AI Start.vi



AI Clear.vi

Figure 3.3.4: The four components of analog data capture

Figure 3.3.5 shows the programmed vi to read in the data from the accelerometer. Within this program, error detection is used to help troubleshoot any errors that may result from the data acquisition. When an error occurs, it is passed from one component to another when one occurs. A notification box appears and displays the error that occurred when the program is halted. Data is

also being appended to a file local on the PC. The data will be stored and used in other applications for analysis. A trigger is also implemented within the vi program. The trigger does not actually tell the program when to start the data acquisition, but it controls when it starts to read in and collect the data. The trigger is set to start on a rising analog voltage above 0 volts. This setting can be specified but for the purposes here, once the voltage is higher the 0 volts the data reading will start. There is also a setting for pre-trigger scans. This allows a specified number of reads, before the trigger started, to be included in the read sequence. The read vi goes back to the buffer and retrieves the number of pre-trigger scans. An example of data retrieved from the accelerometer is displayed in Figure 3.3.6.

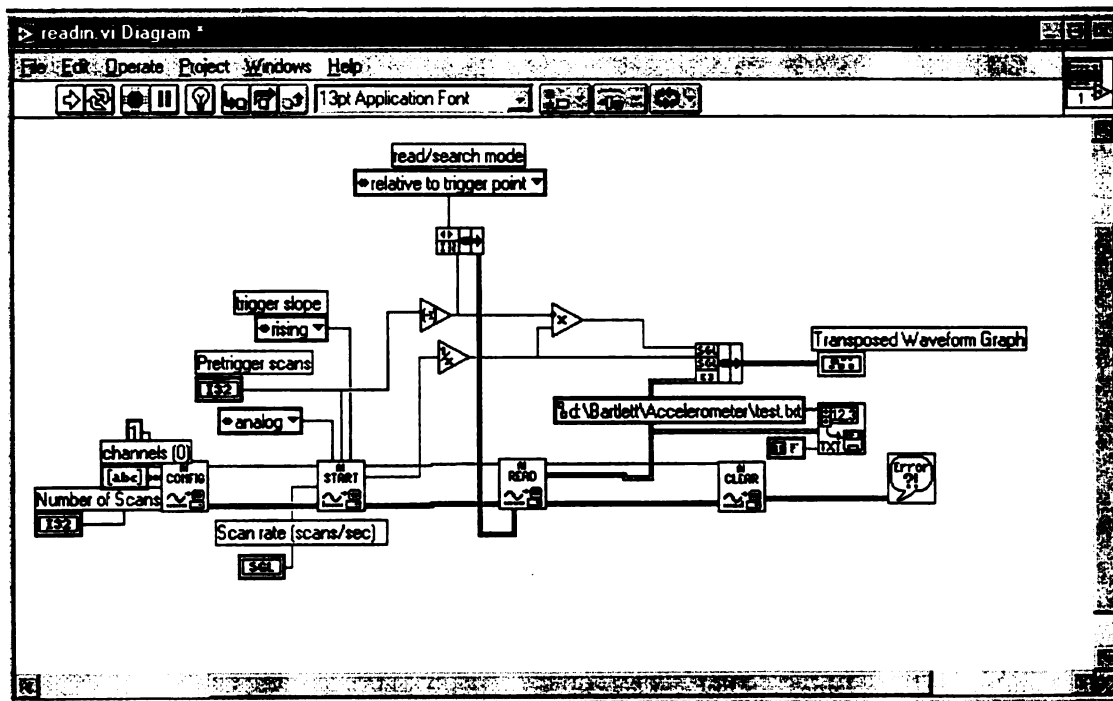


Figure 3.3.5: Diagram view for accelerometer demonstration

Figure 3.3.6 displays the user interface to the vi program. The number of scans, scan rate, pre-trigger scans and the channels are set up so that the user of the program can define the setting for each run of the program. In this example the pre-trigger scan are set to 100. This causes the first 'bounce' that the accelerometer detected is displayed slightly out from the edge of the y-axis. This display shows one second of data containing 2000 samples.

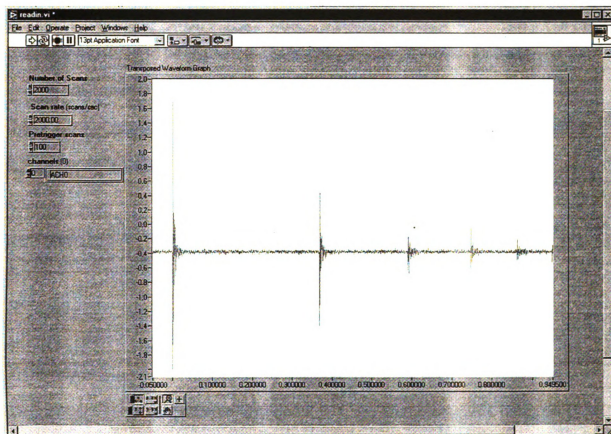


Figure 3.3.6: User interface view for accelerometer demonstration

CONCLUSIONS

The experiment demonstrates the input of a voltage signal from external hardware, saves the data stream to a file and displays the values in a graph

through LabVIEW. It was discovered during this experiment that the all-in-one analog input vi has scan rate limitations. With the required high input rate of the accelerometer four individual vi's are used to separate and speed up the data acquisition process. The four individual vi's were used to configure, start, read and clear the data acquisition port. The desired scan rate of 2000 samples per second was successful.

Saving data to a file is another important piece to the experiment. If any calculations were to be made the actual data, the graph would not be useful for an accurate analysis. Precise readings can not be made by looking at the graph displayed by LabVIEW. In the situation of an accelerometer, a manual or human recording of the data is impossible.

3.4 FREQUENCY MEASUREMENT: TACHOMETER DEMONSTRATION

INTRODUCTION

In this demonstration a wheel is being rotated on a motor and LabVIEW will determine the speed of the wheel and the direction that it is going. There are two sensors located at the bottom of the wheel that can detect when the holes pass through them. Both of these signals generated from the sensors will be read into LabVIEW.

CIRCUIT DESIGN

Figure 4.3.1 displays the schematic for the transmissive optoschmitt sensor used in the demonstration. The two sensors are connected to a +5V power

source and ground. A 180 Ω resistor is placed between Vcc and GND near the device in order to stabilize power supply line.

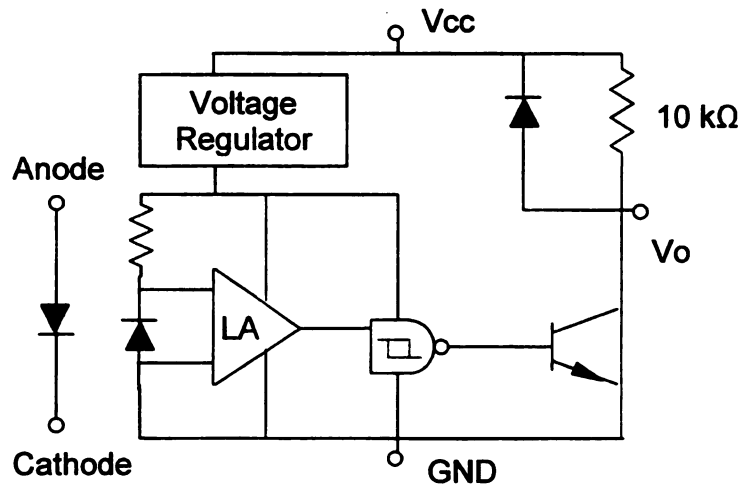


Figure 3.4.1: Schematic for transmissive optoschmitt sensor⁴

HARDWARE

The hardware consists of a large motor mounted to a wooden base. The motor has a round disk mounted to its axle so that when the motor turns the disk will rotate with it. The wheel is 2-5/8 inch diameter and has four 1/8 inch holes drilled into it at 0 degrees, 90 degrees, 180 degrees and 270 degrees 1/16 inch away from the edge. Figure 3.4.2 displays the device.

There are two sensors are mounted on the base along with the motor. The sensors are positioned to allow the disk to pass through them. The sensors are ©Honeywell's HOA2003 Transmissive Optoschmitt Sensors. This sensor consists of an infrared diode facing the photodetector. The spinning disk passes through the two components of the sensor. An internal Schmitt trigger creates a clear signal from each sensor.

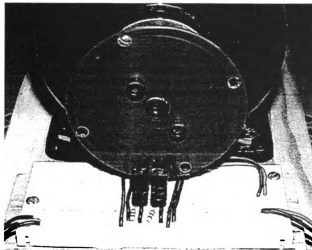


Figure 3.4.2: Spinning wheel with sensors

SOFTWARE

The LabVIEW program for the tachometer is a combination of the thermistor and the accelerometer demonstration. The vi consists of a while loop what will continue until the 'stop' button is pushed as in the thermistor vi. Inside the while loop the four independent vis 'AI Config', 'AI Start', 'AI Read' and 'AI Clear' are used. They are used due to the frequency that our signals are being read in at. The pulse signal generated at very high frequencies will be extremely small due to the size of the holes. Due to this the standard 'AI Read' vi would not be fast enough to acquire an adequate signal.

The wave signals need to be separated in order to analysis and compare the two wavelengths. 'AI Read' component packs the two signals into an array. A 'Index Array' component is used to reference the individual signals. Since the first channel reference in the channel control is 0 then index 0 will reference the signal from this port and respectively index 1 will reference the second signal

from channel 2. The 'Index Array' allows the selection of a single element or sub array to be selected at one time. Because of this feature, two 'Index array' components are needed to reference both signals at the same time.

Once the two signals are separated, they can be compared and analyzed. One desired value is the direction that the disk is rotating. To determine this the phase of the two signals need to be compared. The 'Graph and Calculate Phase Difference' vi, seen in Figure 3.4.3, is used to generate the difference in phase in radians. Internally the vi uses the 'Amplitude and Spectrum' vi as used in the first demonstration to acquire the phase and magnitude of each signal. It then compared the two phases and outputs a number value. That number value is then feed into a comparison to evaluate if the number is positive or negative. If the value is negative then the disk is spinning counter-clockwise; otherwise it is spinning clockwise. A case structure is used to display the results in text to the user depending on the output of the comparison.

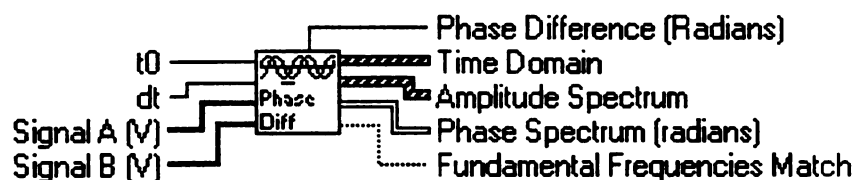


Figure 3.4.3: Graph and calculate phase difference vi

To compute the rotations per second a new component needed is the Power and Frequency vi as seen in Figure 3.4.4. In order to compute the frequency the angular velocity is needed. This is available from the 'Power Spectrum' vi and can be feed into the new vi to compute the frequency. The 'Power and

Frequency' vi calculates the angular velocity into the frequency that we can use in the rotation per second calculation.

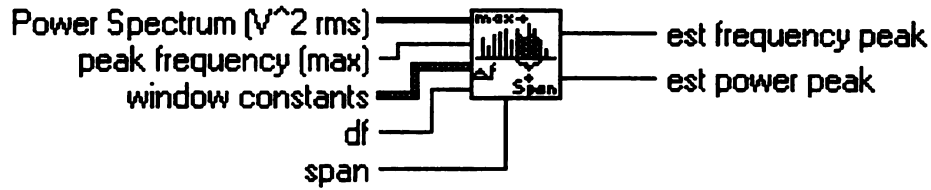


Figure 3.4.4: Power and frequency vi

The Figure 3.4.4 displays the diagram view of the tachometer vi.

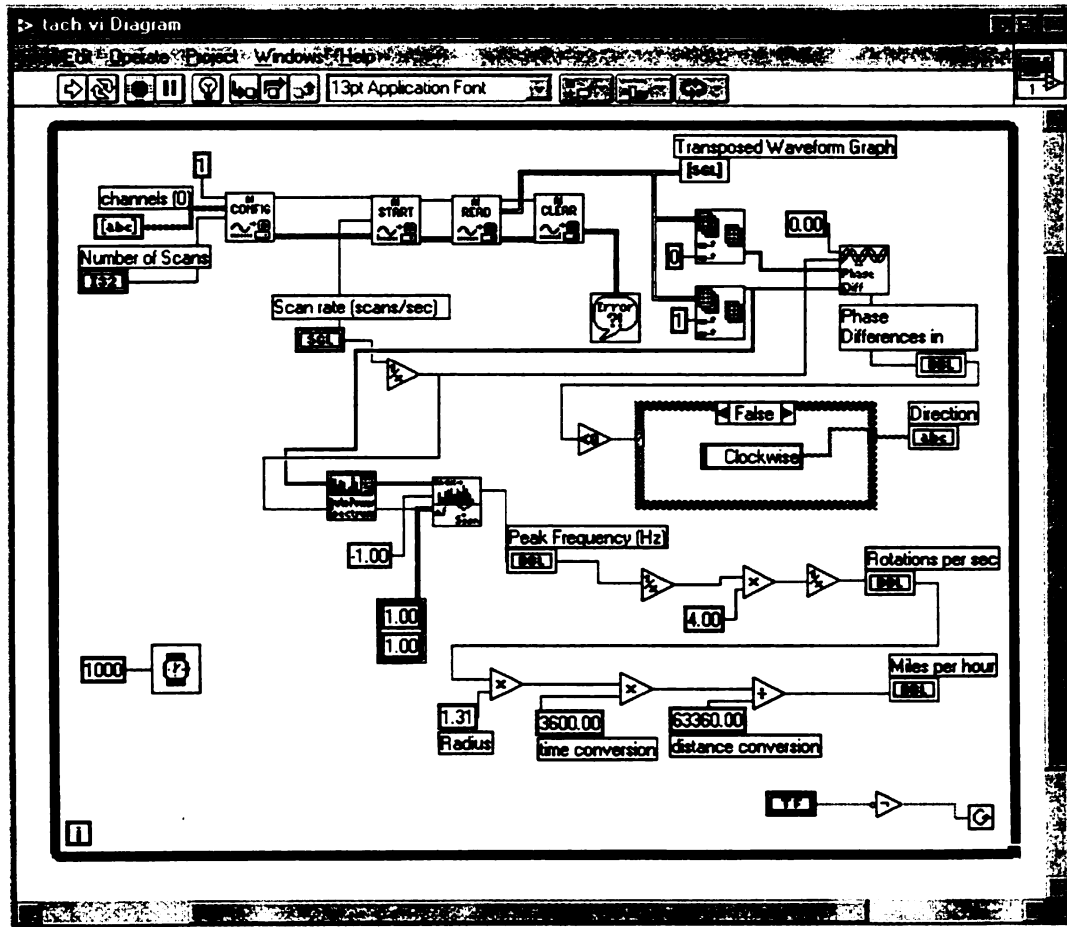


Figure 3.4.4:Diagram view for tachometer demonstration

Within the user interface seen in Figure 3.4.5 two channels have been specified. This value can be changed manually at any time. The device number, one for this demonstration, has been made a constant in the diagram view. Numerous ports can be specified by virtual channel name or by number. Each channel needs to be separated by a comma for correct syntax. Two signals are acquired, one from each sensor. When the hole passes through the sensor, the pulse occurs, creating a square wave.

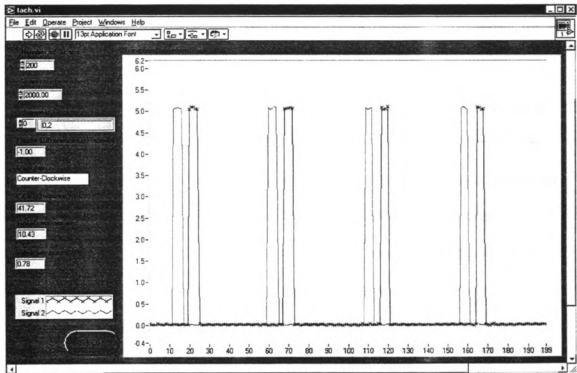


Figure 3.4.5: User interface for tachometer demonstration

CALCULATIONS

The Phase difference vi, calculates the angular speed of the disk. The relation ship of linear speed and angular speed is ,

$$\text{linear speed} = \text{radius} * \text{angular speed.}$$

Angular speed ω in units of radian/second is,

$$\omega = 2\pi f$$

where f is the frequency . Therefore the linear speed s is simply,

$$s = R * \omega$$

where R is the radius of the disk. The value of its linear velocity or miles per hour is a valuable measurement. With the current radius of 1 5/16 inch the value s can be calculated by using the additional conversions shown below.

$$\frac{s(\text{inches})}{1(\text{sec})} \times \frac{1(\text{mile})}{63,360(\text{inches})} \times \frac{3600(\text{sec})}{1(\text{hour})}$$

CONCLUSIONS

This demonstration is a combination of the time domain - signal processing and the frequency domain - accelerometer demonstrations noted earlier in the paper. The same techniques are used to read in the signal in the accelerometer example and the signal processing techniques are used as in the signal processing example. This is a good example of how LabVIEW can build from project to project. Each vi that is created can be used and copied to future vis, code can be reused and plugged into subvis for reuse. The tachometer demonstration displays how we used some of the basic concepts of LabVIEW and incorporated them to display values that are useful to the user.

3.5 INTERFACING: SIMPLE SORT DEMOSTRATION

INTRODUCTION

In this demonstration a LabVIEW vi calls a conventional program source code, a C++ program. The demonstration will show the needed steps and

components needed to call to an external function from within a LabVIEW vi program.

SOFTWARE

The key component in LabVIEW to call out to external code is called the Code Interface Node (CIN) seen in Figure 3.5.1. The code interface node allows you to specify the parameters that are going in and that will be coming out of the specified code. When the vi is compiled and ran, the external code will be called from within the vi and no additional starting or stopping of the external program is necessary. The vi that calls the external code can not be reset until the code has completed executing.

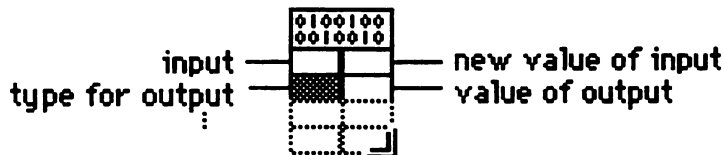


Figure 3.5.1: Code interface node vi

The process to incorporate external code contains two steps. The first step is to compile the desired code in the conventional language that it is written in. Only a handful of conventional programming languages are compatible with LabVIEW and can be imported. A valid list of languages will be available from the National Instruments web site. For the example in this demo, Microsoft Visual C++ is used. First the code must be compiled from within the original language interface. In the case of MS Visual C++ the project must include the sin.obj, labview.lib lvsb.lib, and lvsbmain.def located in the cintolls\win32 directory.

Detailed steps can be found in Appendix G or the National Instruments Corporation LabVIEW Code Interface Reference Manual.

After the code is created and compiled within the external programming language, the *.lsb file is created. The lsb file is the compiled code that LabVIEW uses to run the external code. From within LabVIEW, the lsb file is linked to the code interface node. vi. This file is essential for a working CIN component. The code interface node is the link between the external code and the LabVIEW.

The CIN interface is connected to other components within the vi to obtain and display the parameters. The parameters are added individually and can be used as output only or as input/output parameters. In this demonstration only one parameter set as an input/output variable, the array A, was needed. In Figure 3.5.2, the diagram view shows the creation of a random number array of a specified length. The array is then passed to the CIN. Links on the left side of the CIN are inputs and those on the right side are outputs.

The program that is called is a 'Simple Sort' that moves through the array and organizes its value in ascending order. The figure 3.5.3 displays the results of one sort of an array of length 12. The first array is the original array and the second is the sorted array that was the output from the CIN component. Appendix F displays the source code for the MS Visual C++ program used.

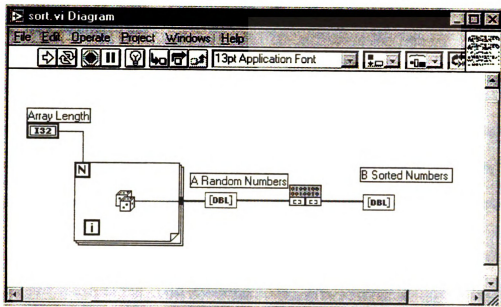


Figure 3.5.2: Diagram view of CIN demonstration

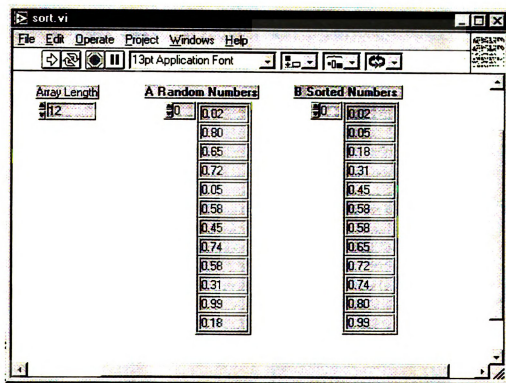


Figure 3.5.3: User interface view of CIN demonstration

CONCLUSIONS

LabVIEW can compile its components in a speedy manner, but LabVIEW can call to more conventional programming languages. The conventional program, such as Visual C++ or Symantec C, may handle the task more easily for applications that are time-critical or require a large amount of data manipulation.

This demonstration performs a simple call to a Visual C++ sort program to show the use of the code interface node. This internal LabVIEW component can be used at more complex levels to speed up and simplify a LabVIEW program. If LabVIEW is replacing any existing testing systems, the old code may, in some circumstances, be used in LabVIEW so programming would not have to be redone when moving to LabVIEW.

Chapter 4: Conclusions

LabVIEW is a software tool currently being used in industry and research. It would be beneficial for any student to learn or at least be familiar with the product before starting out in an industry or research position. The objective of this paper is to give anyone a good understanding of how LabVIEW is used. That knowledge can then be a starting point for future work in LabVIEW at the university or in future industry or research positions.

The demonstrations have displayed a wide range of LabVIEWs capabilities. Firstly, an introduction to electrical engineering concepts and to LabVIEW is needed. The demonstrations then display how to acquire data from an internal and external source, how to save and display that data, what tools to use depending on the rate at which the data is being read, and how to call out to external code if any special need can not be met from within LabVIEW. These concepts are not limited to electrical engineering. Many industries can take advantage of the features that LabVIEW has to offer. The table below highlights the relevant features in each demonstration.

TABLE 4.1: Relevant features for each demonstration	
<u>Demonstration</u>	<u>Feature</u>
Time domain measurement	Signal processing capabilities
Quasistatic measurement	Slow data acquisition over a short or long period of time
Dynamic measurement	Fast data acquisition and the ability to capture data to a file
Frequency measurement	User friendly interfaces and easy to read results
Interfacing	Embed external source code

The features displayed in the demonstrations can be applied to similar types of experiments or simulations. For example, the process of slow data acquisition can be applied to any application requiring data acquisition in a slow and time consuming manner regardless of the type of data that is being collected. The paper can be used as a guideline to the process evolved in putting together an experiment. This can be used additionally to the LabVIEW tutorials that do not include all the components of an experiment, i.e. hardware and software.

Only a fraction of the capabilities of LabVIEW are demonstrated. The extent to which LabVIEW can be expanded upon is limitless. Future work can expand on the current demonstrations or use the tools and concepts shown for completely new and independent applications.

APPENDICES

APPENDIX A

PCI-MIO E SERIES NI-DAQ I/O PIN ASSIGNMENTS⁹

ACH8	34	68	ACH0
ACH1	33	67	AIGND
AIGND	32	66	ACH9
ACH10	31	65	ACH2
ACH3	30	64	AIGND
AIGND	29	63	ACH11
ACH4	28	62	AISENSE
AIGND	27	61	ACH12
ACH13	26	60	ACH5
ACH6	25	59	AIGND
AIGND	24	58	ACH14
ACH15	23	57	ACH7
DAC0OUT	22	56	AIGND
DAC1OUT	21	55	AOGND
EXTREF	20	54	AOGND
DIO4	19	53	DGND
DGND	18	52	DIO0
DIO1	17	51	DIO5
DIO6	16	50	DGND
DGND	15	49	DIO2
+5V	14	48	DIO7
DGND	13	47	DIO3
DGND	12	46	SCANCLK
PFI0/TRIG1	11	45	EXTSTROBE
PFI1/TRIG2	10	44	DGND
DGND	9	43	PFI2/CONVERT
+5V	8	42	PFI3/GPCTR1_SOURCE
DGND	7	41	PFI4/GPCTR1_GATE
PF15/UPDATE	6	40	GPCTR1/OUT
PFI6/WFTRIG	5	39	DGND
DGND	4	38	PF17/STARTSCAN
PFI9/GPCTR0_GATE	3	37	PFI8/GPCTR0_SOURCE
GPCTR0_OUT	2	36	DGND
FREQ_OUT	1	35	DGND

APPENDIX B

THERMISTOR RESISTANCE MEASUREMENTS – TEMPERATURE DEMONSTRATION

Data table of resistance measurements taken of thermistor from 0 to 100 degrees C.

Temp oC	Rt (Ω)	Temp oC	Rt (Ω)
0.0	7291.0	52.5	733.4
2.5	6240.0	55.0	661.6
5.0	5647.0	57.5	605.2
7.5	4972.0	60.0	556.5
10.0	4401.0	62.5	508.4
12.5	3946.0	65.0	458.4
15.0	3452.0	67.5	427.5
17.5	3076.0	70.0	391.3
20.0	2744.0	72.5	362.8
22.5	2495.0	75.0	330.1
25.0	2201.0	77.5	307.0
27.5	2002.0	80.0	283.5
30.0	1786.0	82.5	262.1
32.5	1598.0	85.0	242.1
35.0	1441.0	87.5	227.1
37.5	1322.0	90.0	211.3
40.0	1172.0	92.5	195.1
42.5	1063.0	95.0	180.7
45.0	966.4	97.5	169.8
47.5	882.1	100.0	158.8
50.0	798.3		

APPENDIX C

VOLTAGE READINGS FROM HARDWARE CIRCUIT – TEMPERATURE DEMOSTRATION

Data table of measured circuit values from 0 to 100 degrees C.

Temp °C	Voltage without Gain (V)	Voltage with Gain (V)	Temp °C	Voltage without Gain (V)	Voltage with Gain (V)
0.0	-0.8499	-8.535	50.0	0.7655	7.666
2.5	-0.7220	-7.251	52.5	0.7911	7.915
5.0	-0.5670	-5.582	55.0	0.8164	8.154
7.5	-0.4262	-4.189	57.5	0.8382	8.384
10.0	-0.3123	-3.096	60.0	0.8591	8.598
12.5	-0.1857	-1.802	62.5	0.8775	8.778
15.0	-0.0738	-0.725	65.0	0.8937	8.950
17.5	0.2537	0.303	67.5	0.9099	9.097
20.0	0.1167	1.206	70.0	0.9242	9.248
22.5	0.2056	2.080	72.5	0.9360	9.365
25.0	0.2806	2.817	75.0	0.9479	9.482
27.5	0.3523	3.555	77.5	0.9588	9.590
30.0	0.4179	4.199	80.0	0.9684	9.687
32.5	0.4949	4.971	82.5	0.9771	9.775
35.0	0.5184	5.206	85.0	0.9856	9.854
37.5	0.5756	5.767	87.5	0.9924	9.922
40.0	0.6203	6.216	90.0	0.9990	9.990
42.5	0.6631	6.646	92.5	1.0060	9.997
45.0	0.6996	7.007	95.0	1.0110	10.000
47.5	0.7329	7.334	97.5	1.0150	10.000
			100.0	1.0200	10.000

APPENDIX D

CALCULATED EQUATION VALUES – TEMPERATURE DEMONSTRATION

Data table of calculated circuit measurements from 0 to 100 degrees C.

Temp (°C)	Rt (Ω)	Rxo (Ω)	Δ R (Ω)	R1 (Ω)	R3 (Ω)	R4 (Ω)	V _s (V)	-R1*ΔR(Ω)	V _{out} (V)	Gain	V _{out} *Gain (V)
0.0	7291.0	3200	4091.0	12,000	3,200	12,000	5	-49092000	-0.837	10	-8.371
2.5	6240.0	3200	3040.0	12,000	3,200	12000	5	-36480000	-0.658	10	-6.579
5.0	5647.0	3200	2447.0	12,000	3,200	12000	5	-29364000	-0.547	10	-5.474
7.5	4972.0	3200	1772.0	12,000	3,200	12000	5	-21264000	-0.412	10	-4.121
10.0	4401.0	3200	1201.0	12,000	3,200	12000	5	-14412000	-0.289	10	-2.891
12.5	3946.0	3200	746.0	12,000	3,200	12000	5	-8952000	-0.185	10	-1.847
15.0	3452.0	3200	252.0	12,000	3,200	12000	5	-3024000	-0.064	10	-0.644
17.5	3076.0	3200	-124.0	12,000	3,200	12000	5	1488000	0.032	10	0.325
20.0	2744.0	3200	-456.0	12,000	3,200	12000	5	5472000	0.122	10	1.221
22.5	2495.0	3200	-705.0	12,000	3,200	12000	5	8460000	0.192	10	1.920
25.0	2201.0	3200	-999.0	12,000	3,200	12000	5	11988000	0.278	10	2.777
27.5	2002.0	3200	-1198.0	12,000	3,200	12000	5	14376000	0.338	10	3.377
30.0	1786.0	3200	-1414.0	12,000	3,200	12000	5	16968000	0.405	10	4.049
32.5	1598.0	3200	-1602.0	12,000	3,200	12000	5	19224000	0.465	10	4.650
35.0	1441.0	3200	-1759.0	12,000	3,200	12000	5	21108000	0.517	10	5.166
37.5	1322.0	3200	-1878.0	12,000	3,200	12000	5	22536000	0.556	10	5.565
40.0	1172.0	3200	-2028.0	12,000	3,200	12000	5	24336000	0.608	10	6.077
42.5	1063.0	3200	-2137.0	12,000	3,200	12000	5	25644000	0.646	10	6.458
45.0	966.4	3200	-2233.6	12,000	3,200	12000	5	26803200	0.680	10	6.800
47.5	882.1	3200	-2317.9	12,000	3,200	12000	5	27814800	0.710	10	7.103
50.0	798.3	3200	-2401.7	12,000	3,200	12000	5	28820400	0.741	10	7.408
52.5	733.4	3200	-2466.6	12,000	3,200	12000	5	29599200	0.765	10	7.646
55.0	661.6	3200	-2538.4	12,000	3,200	12000	5	30460800	0.791	10	7.914

Temp (°C)	Rt (Ω)	Rxo (Ω)	$\Delta R(\Omega)$	R1 (Ω)	R3 (Ω)	R4 (Ω)	Vs(V)	-R1*ΔR(Ω)	Vout(V)	Gain	Vout*Gain (V)
57.5	605.2	3200	-2594.8	12,000	3,200	12000	5	31137600	0.813	10	8.126
60.0	556.5	3200	-2643.5	12,000	3,200	12000	5	31722000	0.831	10	8.310
62.5	508.4	3200	-2691.6	12,000	3,200	12000	5	32299200	0.849	10	8.494
65.0	458.4	3200	-2741.6	12,000	3,200	12000	5	32899200	0.869	10	8.687
67.5	427.5	3200	-2772.5	12,000	3,200	12000	5	33270000	0.881	10	8.806
70.0	391.3	3200	-2808.7	12,000	3,200	12000	5	33704400	0.895	10	8.947
72.5	362.8	3200	-2837.2	12,000	3,200	12000	5	34046400	0.906	10	9.059
75.0	330.1	3200	-2869.9	12,000	3,200	12000	5	34438800	0.919	10	9.188
77.5	307.0	3200	-2893.0	12,000	3,200	12000	5	34716000	0.928	10	9.279
80.0	283.5	3200	-2916.5	12,000	3,200	12000	5	34998000	0.937	10	9.372
82.5	262.1	3200	-2937.9	12,000	3,200	12000	5	35254800	0.946	10	9.458
85.0	242.1	3200	-2957.9	12,000	3,200	12000	5	35494800	0.954	10	9.538
87.5	227.1	3200	-2972.9	12,000	3,200	12000	5	35674800	0.960	10	9.598
90.0	211.3	3200	-2988.7	12,000	3,200	12000	5	35864400	0.966	10	9.661
92.5	195.1	3200	-3004.9	12,000	3,200	12000	5	36058800	0.973	10	9.726
95.0	180.7	3200	-3019.3	12,000	3,200	12000	5	36231600	0.978	10	9.785
97.5	169.8	3200	-3030.2	12,000	3,200	12000	5	36362400	0.983	10	9.829
100.0	158.8	3200	-3041.2	12,000	3,200	12000	5	36494400	0.987	10	9.873

APPENDIX E

DATA COLLECTED TO FILE FROM – ACCELEROMETER DEMONSTRATION

Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)
-0.376	0.0005	-0.381	0.0205	-0.381	0.0405	-0.298	0.0605	-0.371	0.0805
-0.381	0.0010	-0.376	0.0210	-0.366	0.0410	-0.459	0.0610	-0.381	0.0810
-0.366	0.0015	-0.381	0.0215	-0.361	0.0415	-0.396	0.0615	-0.396	0.0815
-0.352	0.0020	-0.391	0.0220	-0.366	0.0420	-0.503	0.0620	-0.405	0.0820
-0.352	0.0025	-0.381	0.0225	-0.391	0.0425	-0.356	0.0625	-0.376	0.0825
-0.381	0.0030	-0.371	0.0230	-0.400	0.0430	-0.371	0.0630	-0.356	0.0830
-0.391	0.0035	-0.376	0.0235	-0.400	0.0435	-0.361	0.0635	-0.361	0.0835
-0.381	0.0040	-0.381	0.0240	-0.396	0.0440	-0.278	0.0640	-0.405	0.0840
-0.371	0.0045	-0.366	0.0245	-0.396	0.0445	-0.391	0.0645	-0.366	0.0845
-0.386	0.0050	-0.356	0.0250	-0.386	0.0450	-0.381	0.0650	-0.386	0.0850
-0.391	0.0055	-0.376	0.0255	-0.376	0.0455	-0.415	0.0655	-0.332	0.0855
-0.381	0.0060	-0.400	0.0260	-0.371	0.0460	-0.469	0.0660	-0.376	0.0860
-0.371	0.0065	-0.405	0.0265	-0.381	0.0465	-0.420	0.0665	-0.361	0.0865
-0.376	0.0070	-0.396	0.0270	-0.386	0.0470	-0.376	0.0670	-0.376	0.0870
-0.371	0.0075	-0.391	0.0275	-0.381	0.0475	-0.352	0.0675	-0.361	0.0875
-0.366	0.0080	-0.391	0.0280	-0.371	0.0480	-0.327	0.0680	-0.396	0.0880
-0.361	0.0085	-0.386	0.0285	-0.386	0.0485	-0.308	0.0685	-0.386	0.0885
-0.381	0.0090	-0.371	0.0290	-0.400	0.0490	-0.322	0.0690	-0.381	0.0890
-0.400	0.0095	-0.371	0.0295	-0.400	0.0495	-0.410	0.0695	-0.366	0.0895
-0.405	0.0100	-0.386	0.0300	-0.386	0.0500	-0.415	0.0700	-0.376	0.0900
-0.396	0.0105	-0.386	0.0305	-0.718	0.0505	-0.381	0.0705	-0.376	0.0905
-0.391	0.0110	-0.376	0.0310	0.640	0.0510	-0.327	0.0710	-0.366	0.0910
-0.391	0.0115	-0.376	0.0315	0.605	0.0515	-0.366	0.0715	-0.376	0.0915
-0.386	0.0120	-0.391	0.0320	-0.972	0.0520	-0.352	0.0720	-0.381	0.0920
-0.371	0.0125	-0.405	0.0325	0.757	0.0525	-0.396	0.0725	-0.391	0.0925
-0.376	0.0130	-0.396	0.0330	-0.937	0.0530	-0.332	0.0730	-0.396	0.0930
-0.386	0.0135	-0.386	0.0335	0.420	0.0535	-0.444	0.0735	-0.400	0.0935
-0.386	0.0140	-0.381	0.0340	-0.991	0.0540	-0.381	0.0740	-0.396	0.0940
-0.371	0.0145	-0.376	0.0345	-0.459	0.0545	-0.405	0.0745	-0.391	0.0945
-0.381	0.0150	-0.361	0.0350	-0.283	0.0550	-0.298	0.0750	-0.391	0.0950
-0.391	0.0155	-0.352	0.0355	-0.562	0.0555	-0.396	0.0755	-0.386	0.0955
-0.405	0.0160	-0.366	0.0360	0.186	0.0560	-0.376	0.0760	-0.381	0.0960
-0.391	0.0165	-0.386	0.0365	-0.317	0.0565	-0.420	0.0765	-0.391	0.0965
-0.381	0.0170	-0.381	0.0370	-0.190	0.0570	-0.410	0.0770	-0.391	0.0970
-0.381	0.0175	-0.376	0.0375	-0.425	0.0575	-0.439	0.0775	-0.366	0.0975
-0.371	0.0180	-0.381	0.0380	-0.371	0.0580	-0.430	0.0780	-0.361	0.0980
-0.352	0.0185	-0.391	0.0385	-0.386	0.0585	-0.381	0.0785	-0.371	0.0985
-0.352	0.0190	-0.381	0.0390	-0.566	0.0590	-0.371	0.0790	-0.400	0.0990
-0.376	0.0195	-0.376	0.0395	-0.308	0.0595	-0.371	0.0795	-0.400	0.0995
-0.386	0.0200	-0.371	0.0400	-0.522	0.0600	-0.391	0.0800	-0.376	0.1000

Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)
-0.376	0.1005	-0.381	0.1240	-0.371	0.1475	-0.361	0.1710	-0.391	0.1945
-0.371	0.1010	-0.371	0.1245	-0.361	0.1480	-0.381	0.1715	-0.376	0.1950
-0.361	0.1015	-0.371	0.1250	-0.405	0.1485	-0.396	0.1720	-0.381	0.1955
-0.356	0.1020	-0.366	0.1255	-0.400	0.1490	-0.391	0.1725	-0.386	0.1960
-0.366	0.1025	-0.405	0.1260	-0.386	0.1495	-0.371	0.1730	-0.386	0.1965
-0.376	0.1030	-0.400	0.1265	-0.381	0.1500	-0.376	0.1735	-0.376	0.1970
-0.396	0.1035	-0.405	0.1270	-0.400	0.1505	-0.376	0.1740	-0.371	0.1975
-0.376	0.1040	-0.376	0.1275	-0.381	0.1510	-0.352	0.1745	-0.371	0.1980
-0.371	0.1045	-0.376	0.1280	-0.352	0.1515	-0.347	0.1750	-0.391	0.1985
-0.356	0.1050	-0.376	0.1285	-0.347	0.1520	-0.381	0.1755	-0.391	0.1990
-0.391	0.1055	-0.366	0.1290	-0.376	0.1525	-0.410	0.1760	-0.400	0.1995
-0.381	0.1060	-0.366	0.1295	-0.391	0.1530	-0.405	0.1765	-0.396	0.2000
-0.386	0.1065	-0.400	0.1300	-0.376	0.1535	-0.391	0.1770	-0.400	0.2005
-0.391	0.1070	-0.410	0.1305	-0.376	0.1540	-0.391	0.1775	-0.371	0.2010
-0.381	0.1075	-0.386	0.1310	-0.386	0.1545	-0.391	0.1780	-0.352	0.2015
-0.361	0.1080	-0.376	0.1315	-0.386	0.1550	-0.371	0.1785	-0.342	0.2020
-0.352	0.1085	-0.371	0.1320	-0.366	0.1555	-0.361	0.1790	-0.366	0.2025
-0.386	0.1090	-0.396	0.1325	-0.371	0.1560	-0.381	0.1795	-0.376	0.2030
-0.410	0.1095	-0.376	0.1330	-0.386	0.1565	-0.400	0.1800	-0.386	0.2035
-0.400	0.1100	-0.376	0.1335	-0.391	0.1570	-0.386	0.1805	-0.386	0.2040
-0.391	0.1105	-0.381	0.1340	-0.371	0.1575	-0.366	0.1810	-0.391	0.2045
-0.400	0.1110	-0.391	0.1345	-0.366	0.1580	-0.371	0.1815	-0.386	0.2050
-0.391	0.1115	-0.361	0.1350	-0.376	0.1585	-0.391	0.1820	-0.376	0.2055
-0.381	0.1120	-0.347	0.1355	-0.381	0.1590	-0.391	0.1825	-0.366	0.2060
-0.371	0.1125	-0.371	0.1360	-0.386	0.1595	-0.386	0.1830	-0.371	0.2065
-0.386	0.1130	-0.391	0.1365	-0.391	0.1600	-0.391	0.1835	-0.381	0.2070
-0.396	0.1135	-0.381	0.1370	-0.400	0.1605	-0.400	0.1840	-0.371	0.2075
-0.381	0.1140	-0.371	0.1375	-0.391	0.1610	-0.381	0.1845	-0.361	0.2080
-0.366	0.1145	-0.386	0.1380	-0.381	0.1615	-0.352	0.1850	-0.371	0.2085
-0.376	0.1150	-0.396	0.1385	-0.381	0.1620	-0.347	0.1855	-0.386	0.2090
-0.386	0.1155	-0.381	0.1390	-0.381	0.1625	-0.376	0.1860	-0.391	0.2095
-0.386	0.1160	-0.352	0.1395	-0.381	0.1630	-0.381	0.1865	-0.396	0.2100
-0.371	0.1165	-0.371	0.1400	-0.381	0.1635	-0.371	0.1870	-0.396	0.2105
-0.376	0.1170	-0.376	0.1405	-0.381	0.1640	-0.376	0.1875	-0.396	0.2110
-0.376	0.1175	-0.376	0.1410	-0.376	0.1645	-0.400	0.1880	-0.386	0.2115
-0.347	0.1180	-0.356	0.1415	-0.381	0.1650	-0.396	0.1885	-0.376	0.2120
-0.371	0.1185	-0.391	0.1420	-0.391	0.1655	-0.371	0.1890	-0.371	0.2125
-0.361	0.1190	-0.400	0.1425	-0.400	0.1660	-0.371	0.1895	-0.376	0.2130
-0.420	0.1195	-0.415	0.1430	-0.386	0.1665	-0.386	0.1900	-0.381	0.2135
-0.352	0.1200	-0.366	0.1435	-0.381	0.1670	-0.376	0.1905	-0.381	0.2140
-0.410	0.1205	-0.376	0.1440	-0.376	0.1675	-0.352	0.1910	-0.371	0.2145
-0.361	0.1210	-0.391	0.1445	-0.376	0.1680	-0.361	0.1915	-0.386	0.2150
-0.400	0.1215	-0.391	0.1450	-0.361	0.1685	-0.391	0.1920	-0.405	0.2155
-0.356	0.1220	-0.366	0.1455	-0.356	0.1690	-0.396	0.1925	-0.400	0.2160
-0.396	0.1225	-0.371	0.1460	-0.376	0.1695	-0.386	0.1930	-0.381	0.2165
-0.381	0.1230	-0.400	0.1465	-0.381	0.1700	-0.391	0.1935	-0.381	0.2170
-0.386	0.1235	-0.391	0.1470	-0.376	0.1705	-0.400	0.1940	-0.381	0.2175

Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)
-0.361	0.2180	-0.356	0.2415	-0.400	0.2650	-0.396	0.2885	-0.381	0.3120
-0.342	0.2185	-0.371	0.2420	-0.391	0.2655	-0.376	0.2890	-0.386	0.3125
-0.356	0.2190	-0.391	0.2425	-0.386	0.2660	-0.371	0.2895	-0.386	0.3130
-0.391	0.2195	-0.400	0.2430	-0.391	0.2665	-0.376	0.2900	-0.381	0.3135
-0.391	0.2200	-0.400	0.2435	-0.400	0.2670	-0.381	0.2905	-0.376	0.3140
-0.366	0.2205	-0.400	0.2440	-0.381	0.2675	-0.352	0.2910	-0.376	0.3145
-0.381	0.2210	-0.396	0.2445	-0.356	0.2680	-0.352	0.2915	-0.386	0.3150
-0.391	0.2215	-0.386	0.2450	-0.352	0.2685	-0.381	0.2920	-0.386	0.3155
-0.381	0.2220	-0.371	0.2455	-0.371	0.2690	-0.400	0.2925	-0.400	0.3160
-0.361	0.2225	-0.371	0.2460	-0.381	0.2695	-0.396	0.2930	-0.396	0.3165
-0.371	0.2230	-0.381	0.2465	-0.371	0.2700	-0.391	0.2935	-0.396	0.3170
-0.391	0.2235	-0.386	0.2470	-0.371	0.2705	-0.400	0.2940	-0.381	0.3175
-0.376	0.2240	-0.371	0.2475	-0.386	0.2710	-0.400	0.2945	-0.366	0.3180
-0.347	0.2245	-0.371	0.2480	-0.391	0.2715	-0.381	0.2950	-0.347	0.3185
-0.361	0.2250	-0.386	0.2485	-0.381	0.2720	-0.366	0.2955	-0.361	0.3190
-0.391	0.2255	-0.405	0.2490	-0.381	0.2725	-0.381	0.2960	-0.376	0.3195
-0.400	0.2260	-0.391	0.2495	-0.386	0.2730	-0.391	0.2965	-0.381	0.3200
-0.386	0.2265	-0.381	0.2500	-0.381	0.2735	-0.381	0.2970	-0.376	0.3205
-0.400	0.2270	-0.386	0.2505	-0.366	0.2740	-0.361	0.2975	-0.386	0.3210
-0.410	0.2275	-0.381	0.2510	-0.352	0.2745	-0.376	0.2980	-0.391	0.3215
-0.396	0.2280	-0.352	0.2515	-0.366	0.2750	-0.396	0.2985	-0.381	0.3220
-0.366	0.2285	-0.342	0.2520	-0.386	0.2755	-0.391	0.2990	-0.371	0.3225
-0.371	0.2290	-0.366	0.2525	-0.391	0.2760	-0.386	0.2995	-0.376	0.3230
-0.391	0.2295	-0.391	0.2530	-0.400	0.2765	-0.391	0.3000	-0.381	0.3235
-0.386	0.2300	-0.376	0.2535	-0.405	0.2770	-0.396	0.3005	-0.371	0.3240
-0.371	0.2305	-0.366	0.2540	-0.405	0.2775	-0.376	0.3010	-0.356	0.3245
-0.376	0.2310	-0.386	0.2545	-0.386	0.2780	-0.347	0.3015	-0.366	0.3250
-0.391	0.2315	-0.396	0.2550	-0.376	0.2785	-0.352	0.3020	-0.381	0.3255
-0.396	0.2320	-0.376	0.2555	-0.371	0.2790	-0.371	0.3025	-0.396	0.3260
-0.391	0.2325	-0.361	0.2560	-0.381	0.2795	-0.381	0.3030	-0.391	0.3265
-0.391	0.2330	-0.376	0.2565	-0.386	0.2800	-0.366	0.3035	-0.400	0.3270
-0.396	0.2335	-0.391	0.2570	-0.381	0.2805	-0.376	0.3040	-0.405	0.3275
-0.386	0.2340	-0.361	0.2575	-0.371	0.2810	-0.396	0.3045	-0.396	0.3280
-0.361	0.2345	-0.342	0.2580	-0.381	0.2815	-0.386	0.3050	-0.376	0.3285
-0.356	0.2350	-0.371	0.2585	-0.391	0.2820	-0.371	0.3055	-0.371	0.3290
-0.361	0.2355	-0.400	0.2590	-0.400	0.2825	-0.376	0.3060	-0.381	0.3295
-0.371	0.2360	-0.396	0.2595	-0.391	0.2830	-0.391	0.3065	-0.386	0.3300
-0.376	0.2365	-0.386	0.2600	-0.391	0.2835	-0.381	0.3070	-0.371	0.3305
-0.376	0.2370	-0.400	0.2605	-0.386	0.2840	-0.356	0.3075	-0.371	0.3310
-0.381	0.2375	-0.410	0.2610	-0.376	0.2845	-0.356	0.3080	-0.386	0.3315
-0.386	0.2380	-0.386	0.2615	-0.352	0.2850	-0.381	0.3085	-0.396	0.3320
-0.386	0.2385	-0.361	0.2620	-0.347	0.2855	-0.391	0.3090	-0.391	0.3325
-0.381	0.2390	-0.371	0.2625	-0.371	0.2860	-0.386	0.3095	-0.391	0.3330
-0.381	0.2395	-0.396	0.2630	-0.381	0.2865	-0.396	0.3100	-0.396	0.3335
-0.381	0.2400	-0.386	0.2635	-0.376	0.2870	-0.405	0.3105	-0.386	0.3340
-0.376	0.2405	-0.366	0.2640	-0.376	0.2875	-0.400	0.3110	-0.361	0.3345
-0.356	0.2410	-0.376	0.2645	-0.391	0.2880	-0.376	0.3115	-0.347	0.3350

Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)
-0.356	0.3355	-0.298	0.3590	-0.386	0.3825	-0.381	0.4060	-0.381	0.4295
-0.376	0.3360	-0.439	0.3595	-0.410	0.3830	-0.391	0.4065	-0.381	0.4300
-0.376	0.3365	-0.488	0.3600	-0.405	0.3835	-0.376	0.4070	-0.371	0.4305
-0.371	0.3370	-0.435	0.3605	-0.386	0.3840	-0.352	0.4075	-0.371	0.4310
-0.381	0.3375	-0.464	0.3610	-0.342	0.3845	-0.356	0.4080	-0.386	0.4315
-0.391	0.3380	-0.327	0.3615	-0.342	0.3850	-0.381	0.4085	-0.391	0.4320
-0.381	0.3385	-0.396	0.3620	-0.332	0.3855	-0.396	0.4090	-0.391	0.4325
-0.366	0.3390	-0.342	0.3625	-0.371	0.3860	-0.386	0.4095	-0.396	0.4330
-0.381	0.3395	-0.425	0.3630	-0.391	0.3865	-0.396	0.4100	-0.396	0.4335
-0.391	0.3400	-0.400	0.3635	-0.386	0.3870	-0.410	0.4105	-0.381	0.4340
-0.376	0.3405	-0.400	0.3640	-0.405	0.3875	-0.400	0.4110	-0.356	0.4345
-0.352	0.3410	-0.400	0.3645	-0.366	0.3880	-0.381	0.4115	-0.352	0.4350
-0.366	0.3415	-0.410	0.3650	-0.381	0.3885	-0.371	0.4120	-0.366	0.4355
-0.386	0.3420	-0.356	0.3655	-0.347	0.3890	-0.381	0.4125	-0.376	0.4360
-0.386	0.3425	-0.347	0.3660	-0.386	0.3895	-0.386	0.4130	-0.376	0.4365
-0.381	0.3430	-0.391	0.3665	-0.386	0.3900	-0.371	0.4135	-0.376	0.4370
-0.400	0.3435	-0.415	0.3670	-0.381	0.3905	-0.371	0.4140	-0.391	0.4375
-0.410	0.3440	-0.415	0.3675	-0.366	0.3910	-0.386	0.4145	-0.386	0.4380
-0.391	0.3445	-0.376	0.3680	-0.352	0.3915	-0.396	0.4150	-0.381	0.4385
-0.371	0.3450	-0.386	0.3685	-0.376	0.3920	-0.386	0.4155	-0.371	0.4390
-0.376	0.3455	-0.352	0.3690	-0.376	0.3925	-0.386	0.4160	-0.386	0.4395
-0.391	0.3460	-0.361	0.3695	-0.391	0.3930	-0.391	0.4165	-0.386	0.4400
-0.381	0.3465	-0.337	0.3700	-0.400	0.3935	-0.391	0.4170	-0.376	0.4405
-0.371	0.3470	-0.371	0.3705	-0.420	0.3940	-0.371	0.4175	-0.352	0.4410
-0.376	0.3475	-0.391	0.3710	-0.400	0.3945	-0.352	0.4180	-0.366	0.4415
-0.386	0.3480	-0.420	0.3715	-0.386	0.3950	-0.342	0.4185	-0.381	0.4420
-0.391	0.3485	-0.386	0.3720	-0.366	0.3955	-0.366	0.4190	-0.386	0.4425
-0.386	0.3490	-0.371	0.3725	-0.386	0.3960	-0.381	0.4195	-0.386	0.4430
-0.396	0.3495	-0.361	0.3730	-0.381	0.3965	-0.361	0.4200	-0.400	0.4435
-0.400	0.3500	-0.356	0.3735	-0.381	0.3970	-0.376	0.4205	-0.410	0.4440
-0.391	0.3505	-0.332	0.3740	-0.371	0.3975	-0.391	0.4210	-0.391	0.4445
-0.371	0.3510	-0.327	0.3745	-0.391	0.3980	-0.396	0.4215	-0.371	0.4450
-0.361	0.3515	-0.381	0.3750	-0.405	0.3985	-0.376	0.4220	-0.376	0.4455
-0.356	0.3520	-0.410	0.3755	-0.391	0.3990	-0.376	0.4225	-0.386	0.4460
-0.571	0.3525	-0.405	0.3760	-0.386	0.3995	-0.396	0.4230	-0.381	0.4465
-0.854	0.3530	-0.391	0.3765	-0.391	0.4000	-0.386	0.4235	-0.371	0.4470
0.034	0.3535	-0.396	0.3770	-0.391	0.4005	-0.356	0.4240	-0.371	0.4475
-0.698	0.3540	-0.400	0.3775	-0.366	0.4010	-0.352	0.4245	-0.381	0.4480
0.234	0.3545	-0.376	0.3780	-0.347	0.4015	-0.376	0.4250	-0.386	0.4485
-0.674	0.3550	-0.371	0.3785	-0.352	0.4020	-0.391	0.4255	-0.386	0.4490
-0.225	0.3555	-0.400	0.3790	-0.376	0.4025	-0.391	0.4260	-0.396	0.4495
-0.596	0.3560	-0.415	0.3795	-0.376	0.4030	-0.400	0.4265	-0.400	0.4500
-0.425	0.3565	-0.396	0.3800	-0.366	0.4035	-0.410	0.4270	-0.391	0.4505
-0.288	0.3570	-0.361	0.3805	-0.381	0.4040	-0.400	0.4275	-0.366	0.4510
-0.396	0.3575	-0.376	0.3810	-0.391	0.4045	-0.381	0.4280	-0.352	0.4515
-0.137	0.3580	-0.376	0.3815	-0.386	0.4050	-0.366	0.4285	-0.356	0.4520
-0.332	0.3585	-0.381	0.3820	-0.371	0.4055	-0.376	0.4290	-0.371	0.4525

Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)
-0.376	0.4530	-0.386	0.4765	-0.400	0.5000	-0.547	0.5235	-0.386	0.5470
-0.371	0.4535	-0.410	0.4770	-0.386	0.5005	-0.332	0.5240	-0.405	0.5475
-0.386	0.4540	-0.405	0.4775	-0.361	0.5010	-0.562	0.5245	-0.410	0.5480
-0.391	0.4545	-0.386	0.4780	-0.361	0.5015	-0.303	0.5250	-0.386	0.5485
-0.381	0.4550	-0.371	0.4785	-0.371	0.5020	-0.366	0.5255	-0.371	0.5490
-0.371	0.4555	-0.386	0.4790	-0.376	0.5025	-0.322	0.5260	-0.386	0.5495
-0.376	0.4560	-0.381	0.4795	-0.371	0.5030	-0.254	0.5265	-0.400	0.5500
-0.386	0.4565	-0.371	0.4800	-0.366	0.5035	-0.415	0.5270	-0.386	0.5505
-0.381	0.4570	-0.366	0.4805	-0.386	0.5040	-0.386	0.5275	-0.376	0.5510
-0.356	0.4575	-0.381	0.4810	-0.391	0.5045	-0.449	0.5280	-0.366	0.5515
-0.361	0.4580	-0.391	0.4815	-0.376	0.5050	-0.454	0.5285	-0.371	0.5520
-0.376	0.4585	-0.386	0.4820	-0.376	0.5055	-0.386	0.5290	-0.361	0.5525
-0.386	0.4590	-0.391	0.4825	-0.391	0.5060	-0.410	0.5295	-0.352	0.5530
-0.381	0.4595	-0.400	0.4830	-0.391	0.5065	-0.308	0.5300	-0.361	0.5535
-0.396	0.4600	-0.396	0.4835	-0.371	0.5070	-0.352	0.5305	-0.386	0.5540
-0.410	0.4605	-0.376	0.4840	-0.352	0.5075	-0.381	0.5310	-0.391	0.5545
-0.400	0.4610	-0.356	0.4845	-0.361	0.5080	-0.430	0.5315	-0.386	0.5550
-0.376	0.4615	-0.361	0.4850	-0.376	0.5085	-0.415	0.5320	-0.386	0.5555
-0.371	0.4620	-0.371	0.4855	-0.381	0.5090	-0.425	0.5325	-0.386	0.5560
-0.386	0.4625	-0.371	0.4860	-0.386	0.5095	-0.405	0.5330	-0.371	0.5565
-0.386	0.4630	-0.371	0.4865	-0.405	0.5100	-0.366	0.5335	-0.356	0.5570
-0.371	0.4635	-0.376	0.4870	-0.415	0.5105	-0.327	0.5340	-0.352	0.5575
-0.371	0.4640	-0.381	0.4875	-0.391	0.5110	-0.342	0.5345	-0.371	0.5580
-0.381	0.4645	-0.381	0.4880	-0.371	0.5115	-0.361	0.5350	-0.386	0.5585
-0.396	0.4650	-0.371	0.4885	-0.376	0.5120	-0.400	0.5355	-0.376	0.5590
-0.386	0.4655	-0.381	0.4890	-0.391	0.5125	-0.410	0.5360	-0.386	0.5595
-0.391	0.4660	-0.386	0.4895	-0.381	0.5130	-0.386	0.5365	-0.400	0.5600
-0.400	0.4665	-0.386	0.4900	-0.371	0.5135	-0.376	0.5370	-0.405	0.5605
-0.396	0.4670	-0.371	0.4905	-0.371	0.5140	-0.356	0.5375	-0.391	0.5610
-0.376	0.4675	-0.352	0.4910	-0.391	0.5145	-0.371	0.5380	-0.376	0.5615
-0.356	0.4680	-0.361	0.4915	-0.386	0.5150	-0.352	0.5385	-0.386	0.5620
-0.356	0.4685	-0.376	0.4920	-0.381	0.5155	-0.381	0.5390	-0.391	0.5625
-0.366	0.4690	-0.381	0.4925	-0.391	0.5160	-0.400	0.5395	-0.391	0.5630
-0.376	0.4695	-0.386	0.4930	-0.405	0.5165	-0.415	0.5400	-0.376	0.5635
-0.376	0.4700	-0.405	0.4935	-0.391	0.5170	-0.366	0.5405	-0.376	0.5640
-0.381	0.4705	-0.415	0.4940	-0.371	0.5175	-0.342	0.5410	-0.381	0.5645
-0.391	0.4710	-0.391	0.4945	-0.361	0.5180	-0.342	0.5415	-0.386	0.5650
-0.381	0.4715	-0.371	0.4950	-0.366	0.5185	-0.352	0.5420	-0.386	0.5655
-0.371	0.4720	-0.376	0.4955	-0.366	0.5190	-0.361	0.5425	-0.400	0.5660
-0.371	0.4725	-0.381	0.4960	-0.366	0.5195	-0.391	0.5430	-0.405	0.5665
-0.391	0.4730	-0.376	0.4965	-0.371	0.5200	-0.425	0.5435	-0.400	0.5670
-0.386	0.4735	-0.371	0.4970	-0.386	0.5205	-0.430	0.5440	-0.366	0.5675
-0.366	0.4740	-0.381	0.4975	-0.669	0.5210	-0.391	0.5445	-0.352	0.5680
-0.356	0.4745	-0.391	0.4980	-0.366	0.5215	-0.366	0.5450	-0.352	0.5685
-0.376	0.4750	-0.391	0.4985	-0.415	0.5220	-0.371	0.5455	-0.361	0.5690
-0.381	0.4755	-0.381	0.4990	-0.327	0.5225	-0.381	0.5460	-0.371	0.5695
-0.381	0.4760	-0.391	0.4995	-0.273	0.5230	-0.376	0.5465	-0.371	0.5700

Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)
-0.386	0.5705	-0.410	0.5940	-0.366	0.6175	-0.361	0.6410	-0.366	0.6645
-0.391	0.5710	-0.386	0.5945	-0.366	0.6180	-0.366	0.6415	-0.356	0.6650
-0.381	0.5715	-0.381	0.5950	-0.376	0.6185	-0.381	0.6420	-0.381	0.6655
-0.366	0.5720	-0.381	0.5955	-0.366	0.6190	-0.376	0.6425	-0.415	0.6660
-0.371	0.5725	-0.376	0.5960	-0.352	0.6195	-0.391	0.6430	-0.420	0.6665
-0.386	0.5730	-0.371	0.5965	-0.366	0.6200	-0.400	0.6435	-0.391	0.6670
-0.381	0.5735	-0.371	0.5970	-0.391	0.6205	-0.522	0.6440	-0.366	0.6675
-0.361	0.5740	-0.386	0.5975	-0.386	0.6210	-0.254	0.6445	-0.361	0.6680
-0.361	0.5745	-0.386	0.5980	-0.376	0.6215	-0.396	0.6450	-0.352	0.6685
-0.376	0.5750	-0.386	0.5985	-0.381	0.6220	-0.156	0.6455	-0.356	0.6690
-0.381	0.5755	-0.386	0.5990	-0.400	0.6225	-0.454	0.6460	-0.376	0.6695
-0.371	0.5760	-0.400	0.5995	-0.391	0.6230	-0.327	0.6465	-0.400	0.6700
-0.391	0.5765	-0.396	0.6000	-0.366	0.6235	-0.474	0.6470	-0.400	0.6705
-0.415	0.5770	-0.386	0.6005	-0.361	0.6240	-0.405	0.6475	-0.386	0.6710
-0.410	0.5775	-0.366	0.6010	-0.366	0.6245	-0.342	0.6480	-0.371	0.6715
-0.376	0.5780	-0.361	0.6015	-0.371	0.6250	-0.352	0.6485	-0.371	0.6720
-0.376	0.5785	-0.361	0.6020	-0.371	0.6255	-0.308	0.6490	-0.376	0.6725
-0.391	0.5790	-0.366	0.6025	-0.386	0.6260	-0.366	0.6495	-0.386	0.6730
-0.391	0.5795	-0.371	0.6030	-0.405	0.6265	-0.464	0.6500	-0.381	0.6735
-0.366	0.5800	-0.376	0.6035	-0.415	0.6270	-0.396	0.6505	-0.381	0.6740
-0.371	0.5805	-0.386	0.6040	-0.391	0.6275	-0.415	0.6510	-0.366	0.6745
-0.391	0.5810	-0.391	0.6045	-0.376	0.6280	-0.356	0.6515	-0.366	0.6750
-0.391	0.5815	-0.381	0.6050	-0.386	0.6285	-0.366	0.6520	-0.361	0.6755
-0.376	0.5820	-0.376	0.6055	-0.386	0.6290	-0.332	0.6525	-0.376	0.6760
-0.391	0.5825	-0.386	0.6060	-0.376	0.6295	-0.337	0.6530	-0.391	0.6765
-0.410	0.5830	-0.386	0.6065	-0.376	0.6300	-0.386	0.6535	-0.420	0.6770
-0.400	0.5835	-0.371	0.6070	-0.381	0.6305	-0.410	0.6540	-0.400	0.6775
-0.371	0.5840	-0.356	0.6075	-0.386	0.6310	-0.420	0.6545	-0.396	0.6780
-0.352	0.5845	-0.361	0.6080	-0.376	0.6315	-0.386	0.6550	-0.381	0.6785
-0.356	0.5850	-0.376	0.6085	-0.371	0.6320	-0.386	0.6555	-0.381	0.6790
-0.366	0.5855	-0.381	0.6090	-0.391	0.6325	-0.361	0.6560	-0.371	0.6795
-0.361	0.5860	-0.381	0.6095	-0.410	0.6330	-0.366	0.6565	-0.361	0.6800
-0.371	0.5865	-0.400	0.6100	-0.400	0.6335	-0.332	0.6570	-0.381	0.6805
-0.381	0.5870	-0.415	0.6105	-0.381	0.6340	-0.371	0.6575	-0.386	0.6810
-0.396	0.5875	-0.396	0.6110	-0.366	0.6345	-0.396	0.6580	-0.391	0.6815
-0.376	0.5880	-0.371	0.6115	-0.356	0.6350	-0.410	0.6585	-0.376	0.6820
-0.371	0.5885	-0.376	0.6120	-0.356	0.6355	-0.381	0.6590	-0.391	0.6825
-0.376	0.5890	-0.386	0.6125	-0.366	0.6360	-0.391	0.6595	-0.391	0.6830
-0.396	0.5895	-0.381	0.6130	-0.366	0.6365	-0.386	0.6600	-0.396	0.6835
-0.381	0.5900	-0.361	0.6135	-0.386	0.6370	-0.386	0.6605	-0.371	0.6840
-0.366	0.5905	-0.376	0.6140	-0.386	0.6375	-0.371	0.6610	-0.366	0.6845
-0.361	0.5910	-0.391	0.6145	-0.386	0.6380	-0.381	0.6615	-0.366	0.6850
-0.371	0.5915	-0.391	0.6150	-0.376	0.6385	-0.405	0.6620	-0.371	0.6855
-0.376	0.5920	-0.371	0.6155	-0.381	0.6390	-0.415	0.6625	-0.366	0.6860
-0.376	0.5925	-0.391	0.6160	-0.381	0.6395	-0.376	0.6630	-0.366	0.6865
-0.391	0.5930	-0.405	0.6165	-0.376	0.6400	-0.361	0.6635	-0.376	0.6870
-0.410	0.5935	-0.391	0.6170	-0.366	0.6405	-0.371	0.6640	-0.391	0.6875

Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)
-0.381	0.6880	-0.376	0.7115	-0.361	0.7350	-0.376	0.7585	-0.400	0.7820
-0.371	0.6885	-0.386	0.7120	-0.352	0.7355	-0.371	0.7590	-0.415	0.7825
-0.386	0.6890	-0.381	0.7125	-0.356	0.7360	-0.391	0.7595	-0.410	0.7830
-0.400	0.6895	-0.381	0.7130	-0.381	0.7365	-0.415	0.7600	-0.371	0.7835
-0.381	0.6900	-0.376	0.7135	-0.400	0.7370	-0.415	0.7605	-0.361	0.7840
-0.356	0.6905	-0.513	0.7140	-0.386	0.7375	-0.386	0.7610	-0.356	0.7845
-0.361	0.6910	-0.386	0.7145	-0.371	0.7380	-0.361	0.7615	-0.366	0.7850
-0.376	0.6915	-0.352	0.7150	-0.371	0.7385	-0.386	0.7620	-0.366	0.7855
-0.371	0.6920	-0.342	0.7155	-0.386	0.7390	-0.386	0.7625	-0.381	0.7860
-0.366	0.6925	-0.381	0.7160	-0.381	0.7395	-0.371	0.7630	-0.396	0.7865
-0.391	0.6930	-0.439	0.7165	-0.376	0.7400	-0.371	0.7635	-0.391	0.7870
-0.415	0.6935	-0.400	0.7170	-0.381	0.7405	-0.391	0.7640	-0.366	0.7875
-0.405	0.6940	-0.435	0.7175	-0.376	0.7410	-0.391	0.7645	-0.371	0.7880
-0.371	0.6945	-0.352	0.7180	-0.371	0.7415	-0.376	0.7650	-0.366	0.7885
-0.376	0.6950	-0.361	0.7185	-0.366	0.7420	-0.371	0.7655	-0.391	0.7890
-0.391	0.6955	-0.352	0.7190	-0.376	0.7425	-0.405	0.7660	-0.386	0.7895
-0.386	0.6960	-0.312	0.7195	-0.400	0.7430	-0.410	0.7665	-0.396	0.7900
-0.361	0.6965	-0.381	0.7200	-0.405	0.7435	-0.381	0.7670	-0.371	0.7905
-0.376	0.6970	-0.400	0.7205	-0.400	0.7440	-0.361	0.7675	-0.361	0.7910
-0.391	0.6975	-0.410	0.7210	-0.396	0.7445	-0.371	0.7680	-0.352	0.7915
-0.386	0.6980	-0.410	0.7215	-0.391	0.7450	-0.371	0.7685	-0.361	0.7920
-0.366	0.6985	-0.361	0.7220	-0.386	0.7455	-0.352	0.7690	-0.366	0.7925
-0.386	0.6990	-0.400	0.7225	-0.366	0.7460	-0.352	0.7695	-0.400	0.7930
-0.415	0.6995	-0.352	0.7230	-0.366	0.7465	-0.381	0.7700	-0.410	0.7935
-0.405	0.7000	-0.356	0.7235	-0.376	0.7470	-0.396	0.7705	-0.410	0.7940
-0.371	0.7005	-0.356	0.7240	-0.386	0.7475	-0.376	0.7710	-0.386	0.7945
-0.366	0.7010	-0.376	0.7245	-0.386	0.7480	-0.420	0.7715	-0.381	0.7950
-0.371	0.7015	-0.396	0.7250	-0.391	0.7485	-0.356	0.7720	-0.371	0.7955
-0.366	0.7020	-0.381	0.7255	-0.396	0.7490	-0.430	0.7725	-0.371	0.7960
-0.356	0.7025	-0.386	0.7260	-0.400	0.7495	-0.288	0.7730	-0.366	0.7965
-0.376	0.7030	-0.376	0.7265	-0.391	0.7500	-0.435	0.7735	-0.381	0.7970
-0.391	0.7035	-0.405	0.7270	-0.381	0.7505	-0.391	0.7740	-0.396	0.7975
-0.386	0.7040	-0.381	0.7275	-0.366	0.7510	-0.420	0.7745	-0.391	0.7980
-0.371	0.7045	-0.376	0.7280	-0.366	0.7515	-0.371	0.7750	-0.376	0.7985
-0.371	0.7050	-0.396	0.7285	-0.361	0.7520	-0.356	0.7755	-0.386	0.7990
-0.386	0.7055	-0.405	0.7290	-0.366	0.7525	-0.386	0.7760	-0.400	0.7995
-0.391	0.7060	-0.391	0.7295	-0.366	0.7530	-0.361	0.7765	-0.400	0.8000
-0.376	0.7065	-0.361	0.7300	-0.371	0.7535	-0.386	0.7770	-0.376	0.8005
-0.371	0.7070	-0.366	0.7305	-0.381	0.7540	-0.400	0.7775	-0.371	0.8010
-0.366	0.7075	-0.386	0.7310	-0.386	0.7545	-0.391	0.7780	-0.371	0.8015
-0.366	0.7080	-0.371	0.7315	-0.376	0.7550	-0.430	0.7785	-0.366	0.8020
-0.366	0.7085	-0.371	0.7320	-0.381	0.7555	-0.376	0.7790	-0.352	0.8025
-0.376	0.7090	-0.405	0.7325	-0.396	0.7560	-0.376	0.7795	-0.361	0.8030
-0.391	0.7095	-0.430	0.7330	-0.396	0.7565	-0.352	0.7800	-0.381	0.8035
-0.405	0.7100	-0.386	0.7335	-0.366	0.7570	-0.371	0.7805	-0.386	0.8040
-0.405	0.7105	-0.361	0.7340	-0.356	0.7575	-0.381	0.7810	-0.376	0.8045
-0.391	0.7110	-0.352	0.7345	-0.361	0.7580	-0.376	0.7815	-0.376	0.8050

Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)
-0.391	0.8055	-0.381	0.8290	-0.332	0.8525	-0.376	0.8760	-0.400	0.8995
-0.391	0.8060	-0.376	0.8295	-0.371	0.8530	-0.405	0.8765	-0.396	0.9000
-0.371	0.8065	-0.381	0.8300	-0.396	0.8535	-0.410	0.8770	-0.400	0.9005
-0.361	0.8070	-0.396	0.8305	-0.400	0.8540	-0.400	0.8775	-0.386	0.9010
-0.366	0.8075	-0.386	0.8310	-0.381	0.8545	-0.391	0.8780	-0.371	0.9015
-0.371	0.8080	-0.371	0.8315	-0.386	0.8550	-0.391	0.8785	-0.337	0.9020
-0.371	0.8085	-0.366	0.8320	-0.386	0.8555	-0.381	0.8790	-0.342	0.9025
-0.371	0.8090	-0.391	0.8325	-0.371	0.8560	-0.352	0.8795	-0.371	0.9030
-0.396	0.8095	-0.405	0.8330	-0.361	0.8565	-0.366	0.8800	-0.391	0.9035
-0.410	0.8100	-0.391	0.8335	-0.371	0.8570	-0.386	0.8805	-0.396	0.9040
-0.400	0.8105	-0.376	0.8340	-0.376	0.8575	-0.391	0.8810	-0.381	0.9045
-0.376	0.8110	-0.376	0.8345	-0.381	0.8580	-0.381	0.8815	-0.381	0.9050
-0.415	0.8115	-0.371	0.8350	-0.371	0.8585	-0.386	0.8820	-0.381	0.9055
-0.356	0.8120	-0.352	0.8355	-0.381	0.8590	-0.405	0.8825	-0.371	0.9060
-0.366	0.8125	-0.352	0.8360	-0.391	0.8595	-0.400	0.8830	-0.366	0.9065
-0.332	0.8130	-0.376	0.8365	-0.400	0.8600	-0.376	0.8835	-0.366	0.9070
-0.386	0.8135	-0.391	0.8370	-0.391	0.8605	-0.366	0.8840	-0.376	0.9075
-0.396	0.8140	-0.386	0.8375	-0.391	0.8610	-0.376	0.8845	-0.371	0.9080
-0.400	0.8145	-0.371	0.8380	-0.391	0.8615	-0.376	0.8850	-0.371	0.9085
-0.396	0.8150	-0.386	0.8385	-0.396	0.8620	-0.356	0.8855	-0.381	0.9090
-0.361	0.8155	-0.396	0.8390	-0.381	0.8625	-0.371	0.8860	-0.391	0.9095
-0.410	0.8160	-0.381	0.8395	-0.371	0.8630	-0.381	0.8865	-0.400	0.9100
-0.381	0.8165	-0.361	0.8400	-0.371	0.8635	-0.376	0.8870	-0.396	0.9105
-0.352	0.8170	-0.366	0.8405	-0.381	0.8640	-0.361	0.8875	-0.386	0.9110
-0.381	0.8175	-0.371	0.8410	-0.376	0.8645	-0.352	0.8880	-0.396	0.9115
-0.381	0.8180	-0.371	0.8415	-0.376	0.8650	-0.386	0.8885	-0.405	0.9120
-0.386	0.8185	-0.366	0.8420	-0.386	0.8655	-0.400	0.8890	-0.386	0.9125
-0.361	0.8190	-0.381	0.8425	-0.410	0.8660	-0.396	0.8895	-0.366	0.9130
-0.366	0.8195	-0.420	0.8430	-0.400	0.8665	-0.371	0.8900	-0.366	0.9135
-0.386	0.8200	-0.439	0.8435	-0.400	0.8670	-0.361	0.8905	-0.376	0.9140
-0.366	0.8205	-0.376	0.8440	-0.361	0.8675	-0.361	0.8910	-0.376	0.9145
-0.376	0.8210	-0.376	0.8445	-0.366	0.8680	-0.347	0.8915	-0.381	0.9150
-0.371	0.8215	-0.361	0.8450	-0.342	0.8685	-0.361	0.8920	-0.400	0.9155
-0.405	0.8220	-0.400	0.8455	-0.356	0.8690	-0.391	0.8925	-0.410	0.9160
-0.396	0.8225	-0.381	0.8460	-0.376	0.8695	-0.415	0.8930	-0.396	0.9165
-0.381	0.8230	-0.386	0.8465	-0.405	0.8700	-0.420	0.8935	-0.371	0.9170
-0.371	0.8235	-0.400	0.8470	-0.405	0.8705	-0.391	0.8940	-0.361	0.9175
-0.361	0.8240	-0.376	0.8475	-0.371	0.8710	-0.381	0.8945	-0.361	0.9180
-0.352	0.8245	-0.366	0.8480	-0.361	0.8715	-0.381	0.8950	-0.356	0.9185
-0.361	0.8250	-0.352	0.8485	-0.371	0.8720	-0.376	0.8955	-0.356	0.9190
-0.376	0.8255	-0.386	0.8490	-0.376	0.8725	-0.371	0.8960	-0.381	0.9195
-0.400	0.8260	-0.415	0.8495	-0.391	0.8730	-0.386	0.8965	-0.391	0.9200
-0.415	0.8265	-0.400	0.8500	-0.376	0.8735	-0.400	0.8970	-0.386	0.9205
-0.415	0.8270	-0.391	0.8505	-0.386	0.8740	-0.391	0.8975	-0.371	0.9210
-0.386	0.8275	-0.381	0.8510	-0.376	0.8745	-0.376	0.8980	-0.371	0.9215
-0.376	0.8280	-0.371	0.8515	-0.366	0.8750	-0.366	0.8985	-0.376	0.9220
-0.376	0.8285	-0.347	0.8520	-0.352	0.8755	-0.386	0.8990	-0.381	0.9225

Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)	Voltage (V)	Time (sec)
-0.381	0.9230	-0.381	0.9395	-0.381	0.9560	-0.386	0.9725	-0.386	0.9890
-0.376	0.9235	-0.376	0.9400	-0.371	0.9565	-0.371	0.9730	-0.376	0.9895
-0.381	0.9240	-0.381	0.9405	-0.376	0.9570	-0.371	0.9735	-0.371	0.9900
-0.371	0.9245	-0.371	0.9410	-0.366	0.9575	-0.381	0.9740	-0.381	0.9905
-0.356	0.9250	-0.352	0.9415	-0.361	0.9580	-0.371	0.9745	-0.366	0.9910
-0.361	0.9255	-0.356	0.9420	-0.361	0.9585	-0.356	0.9750	-0.361	0.9915
-0.386	0.9260	-0.386	0.9425	-0.381	0.9590	-0.366	0.9755	-0.371	0.9920
-0.405	0.9265	-0.405	0.9430	-0.400	0.9595	-0.400	0.9760	-0.391	0.9925
-0.405	0.9270	-0.400	0.9435	-0.405	0.9600	-0.410	0.9765	-0.405	0.9930
-0.396	0.9275	-0.400	0.9440	-0.396	0.9605	-0.396	0.9770	-0.400	0.9935
-0.391	0.9280	-0.396	0.9445	-0.386	0.9610	-0.391	0.9775	-0.391	0.9940
-0.391	0.9285	-0.396	0.9450	-0.386	0.9615	-0.396	0.9780	-0.391	0.9945
-0.381	0.9290	-0.376	0.9455	-0.381	0.9620	-0.391	0.9785	-0.386	0.9950
-0.366	0.9295	-0.366	0.9460	-0.371	0.9625	-0.371	0.9790	-0.381	0.9955
-0.371	0.9300	-0.376	0.9465	-0.371	0.9630	-0.366	0.9795	-0.371	0.9960
-0.386	0.9305	-0.386	0.9470	-0.381	0.9635	-0.386	0.9800	-0.381	0.9965
-0.381	0.9310	-0.381	0.9475	-0.386	0.9640	-0.396	0.9805	-0.386	0.9970
-0.371	0.9315	-0.376	0.9480	-0.376	0.9645	-0.376	0.9810	-0.381	0.9975
-0.386	0.9320	-0.381	0.9485	-0.376	0.9650	-0.371	0.9815	-0.371	0.9980
-0.405	0.9325	-0.400	0.9490	-0.386	0.9655	-0.386	0.9820	-0.376	0.9985
-0.405	0.9330	-0.396	0.9495	-0.405	0.9660	-0.405	0.9825	-0.391	0.9990
-0.376	0.9335	-0.386	0.9500	-0.396	0.9665	-0.396	0.9830	-0.405	0.9995
-0.366	0.9340	-0.376	0.9505	-0.376	0.9670	-0.376	0.9835		
-0.371	0.9345	-0.381	0.9510	-0.371	0.9675	-0.381	0.9840		
-0.366	0.9350	-0.366	0.9515	-0.376	0.9680	-0.381	0.9845		
-0.347	0.9355	-0.352	0.9520	-0.361	0.9685	-0.361	0.9850		
-0.366	0.9360	-0.356	0.9525	-0.347	0.9690	-0.347	0.9855		
-0.391	0.9365	-0.381	0.9530	-0.366	0.9695	-0.366	0.9860		
-0.391	0.9370	-0.381	0.9535	-0.391	0.9700	-0.386	0.9865		
-0.366	0.9375	-0.376	0.9540	-0.386	0.9705	-0.381	0.9870		
-0.366	0.9380	-0.376	0.9545	-0.371	0.9710	-0.371	0.9875		
-0.381	0.9385	-0.386	0.9550	-0.376	0.9715	-0.381	0.9880		
-0.391	0.9390	-0.386	0.9555	-0.391	0.9720	-0.396	0.9885		

APPENDIX F

MS VISUAL C++ SOURCE CODE FOR CIN DEMONSTRATION

```
/* CIN source file */

#include "extcode.h"

/* typedefs */

typedef struct {
    int32 dimSize;
    float64 arg1[1];
} TD1;
typedef TD1 **TD1Hdl;

CIN MgErr CINRun(TD1Hdl A);

CIN MgErr CINRun(TD1Hdl A) {

    float64 Temp;
    int I;
    int J;
    int32 colSize = (**A).dimSize;

    /*      (**A).dimSize = *Array_Length;*/

    for (I=0; I< colSize-1; I++)
    {
        for (J= colSize-1; J>I; J--)
        {
            if ((**A).arg1[J-1] > (**A).arg1[J])
            {
                Temp      = (**A).arg1[J-1];
                (**A).arg1[J-1] = (**A).arg1[J];
                (**A).arg1[J] = Temp;
            }
        }
    }

    return noErr;
}
```

APPENDIX G

TUTORIALS

Creating virtual Channel names in LabVIEW

Once the device is installed, the channel that you would like to use can be defined. There are 68 pins that the Ni-DAQ can interface with and they range from grounds, analog input, analog output, digital input, digital output, plus many others. Check the data sheet to determine the channel that best fits your application. For our purposes an analog input was need so channel ACH0, pin number 68 was used.

To configure the channel to be used with LabVIEW:

1. Open a project in LabVIEW.
2. Click on 'Project' in the main menu bar and choose the option 'DAQ Wizards'.
3. Under the DAQ Wizards menu choose the first option 'DAQ Channel Wizard'.
4. This will open a second window. Within the right window pane double click on 'Data Neighborhood'.
5. This will open the Data Neighborhood folder. If there are already channels defined, they will be displayed here. You may want to remove and recreate the channel you are planning on using in case it is not configured correctly for your needs.

6. Click with the right mouse button within the Data Neighborhood window.
7. A menu box will appear and you will need to choose 'insert'
8. An insert new box will appear, choose the 'Virtual Channel' option and click okay.
9. The wizard will now continue to ask you a couple questions about the parameters you would like to set for this channel; what type of channel (analog or digital), name, input or output, etc.

For each channel (or pin) that a virtual name wishes to be set for, the above steps must be done for each one.

Setting up MS Visual C++ for use with a CIN

The following is a list of steps to create and configure the external source code needed to interface with the LabVIEW CIN component. A skeleton of a c file can be created in LabVIEW by right mouse clicking over the CIN component. The LabVIEW CIN component must have all the parameters specified before continuing. This c file will contain the header and parameter definitions needed to interface with LabVIEW. This file can also be manually created.

In order to use MS Visual C++ code with the CIN interface the following steps need to be completed from within the MS Visual C++ environment.

1. Open a new 'DLL Project' within MS Visual C++. Under 'File' and then 'New', select the type 'Win32 Dynamic Link Library', and type in a name for your project.

2. Add the needed objects and libraries for CIN. Under menu option 'Project' select 'Add to Project'. Add cin.obj, labview.lib, lvsb.lib and lvsbmain.def to the project. All files are located in the c:\program files\LabVIEW\cintools directory.
3. Edit project setting for the MS Visual C++ Project. Under the menu option of 'Project' select the 'Settings' option. Change the 'Setting for' field to read "All Configurations" for all project settings. When the setting window appears click on the "C/C++" tab.
 - Set the 'Category' field to "Code Generation" and change the 'Use run time library' to state "Multithreaded DLL" and the 'Struct member alignment' field to read "1 Byte".
4. Change to the 'Custom Build' tab within the same window. Add in the 'Command' field to read
`<your cintools path>\win32\lvsbutil$(TargetName) -d "$(WkspDir)$(OutDir)"`
and the 'Output Files' to read
`$(OutDir)$(TargetName).lsb`
5. Open the c file created by LabVIEW from within your new MS Visual C++ project. Add your code into the specified area.
6. Compile the code by clicking on the menu option 'Build' and then 'Compile filename.c'.
7. Once the code is compiled again click on the menu option 'Build' and select the 'Build Projectname.dll'. This process will create the lsb file needed in LabVIEW. It will be located in the c:\Program Files\DevStudio\MyProject\ProjectName\Debug directory.

BIBLIOGRAPHY

Bibliography

- ¹Ambardar, Ashok, Analog and Digital Signal Processing. PWS Publishing Company, 1995
- ²Analog Devices, Precision Instrumentation Amplifier Specifications Sheet, Norwood, MA [Online] Jan. 2000, Available: <http://www.analog.com/>
- ³EG&G IC Sensors, Models 3022 and 3028 Accelerometer Specification Sheet, Milpitas, California [Online] Jan. 2000, Available <http://www.egginc.com/>
- ⁴Honeywell, Transmissive Optoschmitt Sensors Specification Sheet [Online] Available Dec. 1999, <http://www.honeywell.com>, Keyword Search: 'HOA2003'
- ⁵Johnson, Gary W., LabVIEW Graphical Programming, Practical Applications in Instrument and Control. McGraw-Hill Inc. 1994.
- ⁶Lathi, B.P., Linear Systems and Signals. Berkeley-Cambridge Press, Carmichael, California, 1992
- ⁷Matlab Help Desk, Available in version 5.3.
- ⁸National Instruments Web Page. [Online] Available Dec. 1999, <http://www.ni.com/>
- ⁹PCI-MIO E Series User Manual, National Instruments Corporation. [Online] Available Dec. 1999, <http://www.ni.com>, Keyword Search 'PCI E Series User'
- ¹⁰Wells, Lisa K. and Travis, Jeffery, LabVIEW for Everyone, Graphical Programming Made Even Easier. Prentice Hall PTR, NJ 1997

MICHIGAN STATE UNIV. LIBRARIES



31293020589895